NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

A SATELLITE BASED FOG STUDY OF THE KOREAN PENINSULA

by

David K. McDonald

June 2007

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2007	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE A Satellite Based Fog Study of the Korean Peninsula

5. FUNDING NUMBERS

6. AUTHOR(S) David K. McDonald

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

Fog has always been a difficult phenomenon to forecast. Its unpredictable nature and propensity to quickly decrease visibilities have had adverse effects on military operations for many years across the Korean peninsula. It is particularly difficult to prepare forecasts or plan operations for remote locations with limited fog detection ability. For detection at night, over large areas, and in remote locations, satellite observations are the best solution.

This thesis used NASA MODIS satellite imagery to create an abbreviated climatology data set for remote areas across the Korean peninsula. Imagery from the Terra and Aqua near-polar orbiting satellites was used, providing four images per day: one daytime and one nighttime pass for each satellite. Two decision trees were developed to use as guidelines for fog detection by daytime and nighttime satellite images. It was not always possible to unambiguously determine if fog was in each scene, so various categories were created to supplement a fog or no fog decision. The four mid-season months (October 2005, January 2006, April 2006, and July 2006), were analyzed to create a climatology database. The results are tabulated using different variables to make useful comparisons, like day-versus-night or Terra-versus-Aqua. The new totals are compared visually with bar charts and statistically to identify trends that might give insight to planners and forecasters. Seasonal and nocturnal patterns are very evident while differences between the results from two satellites are less obvious. Future work is needed to expand the climatology and increase the statistical results from this study.

14. SUBJECT TERMS
Korea, fog, satellite, MODIS, Terra, Aqua, climatology, brightness temperature, dual channel difference, snow enhancement, nighttime fog detection, daytime fog detection

15. NUMBER OF PAGES 137

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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A SATELLITE BASED FOG STUDY OF THE KOREAN PENINSULA

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY

from the

NAVAL POSTGRADUATE SCHOOL
June 2007

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ACKNOWLEDGMENTS

I would like to thank my co-advisors, Meteorology Department Chairman Philip A. Durkee and Professor Qing Wang, for their leadership and guidance throughout the development of this thesis. Their combined expertise in remote sensing and boundary-layer structure, as they pertain to fog were the perfect fit for this study. Additionally, I would like to thank Kurt Nieslen for his contributions as a third reader, satellite expert, and overall sounding board for my ideas.

I also want to mention the other individuals that had impacts on this thesis: Hway-Jen Chen, NPS (model data manipulation); Capt. Charles Pearcy and the 607th Weather Squadron (coordination and data collection); Dr. Scott Applequist, Mr Gary Swanson, Mr. Mike Hunsucker, and the entire AFCCC team (MASS model simulations, climatology data, and background resources); and the Thesis Processing Office at NPS. Without their help, this thesis work would not have been possible.

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I. INTRODUCTION

A. MILITARY SIGNIFICANCE AND GOALS

1. Significance of Fog

Fog has always been a difficult phenomenon to forecast. Even though there have been many studies done in the U.S. and Europe, and much has been learned about the dynamics of fog for these regions over the past two decades, there have only been a few fog studies completed for Korea. The interest in fog forecasting in Korea increased after the industrial growth and transportation needs expanded around the peninsula. There was a significant rise in the number of collisions, delays, and other incidents on land and at sea due to fog (Cho et al. 1999; Kim and Lee 1970). The limited data and understanding of fog in this region along with the complex terrain of Korea make accurate forecasting extremely difficult.

The Korean peninsula extends from about 43˚ N to 33˚ N. Its northern border is shared with China and Russia, but water surrounds the peninsula on all other sides. The Japan Sea is to the east, the Yellow (West) Sea is on the west and the Korean Straight borders on the south. Hills and mountains cover 75 percent of the peninsula with some peaks in the northeast reaching 2100 meters (7000 feet) but most of the hills and mountains across the rest of the peninsula are below 1500 meters (5000 feet) (AFCCC 2007). Figure 1 displayed an aerial view of the topography across the Korean peninsula.

Figure 1. An aerial view depicting the topography of the Korean peninsula.

According to climatology briefs from the Air Force Combat Climatology Center (AFCCC) website (AFCCC 2007), fog was seen year-round, with visibilities often below one mile. The result: significant impacts to the planning and execution of military operations in the region. Fog has been the most frequent cause of ground visibilities decreasing below three miles (FAA and Dept. of Commerce 1965), and stratus clouds have often created ceilings below flight minimums. According to Venne (1997), fog and low stratus are near-surface phenomena and are a hazard to aviation primarily on takeoffs and landings. Low clouds can also obscure targets at other locations during a mission. When visibilities decrease further it has an adverse affect on all operations in the air and on the ground. The forecasters for the 607th Weather Squadron (WS) noticed several

“choke points” where fog lingered beyond the normal dissipation period seen at other areas. The forecasters have often predicted the fog across the peninsula to dissipate during the day only to see it linger at a few isolated locations. These locations have had a severe impact on operations. As a result of missed fog forecasts there were 50 cancelled missions in 2004 and 124 weather cancels in 2005, for the 2nd Battalion, 2nd Aviation Regiment at Seoul Airfield, Korea alone. These cancelled missions represented 27 percent of the aircraft supported by the 607 WS. Hence the impact of fog on operations across the entire peninsula is evident. Often the ’choke points’ were in remote areas with no surface observations or other meteorological data available. This put a greater dependence on forecast models and satellite imagery for predicting visibilities at these locations.

2. Focus of Study

This study, as requested by the 607 WS, investigated fog across the Korean peninsula with satellite imagery. The goals of the study were to develop techniques for identifying fog with satellite imagery, analyze the available archived images and produce a climatology data set for the remote locations selected. Finally the plan was to use the results to identify trends in the fog development and dissipation.

There were many challenges associated with this fog study. Archived high-resolution geostationary images that provided a continuous scan over the region were not available. MODIS satellite data was a good substitute but only provided four images per day. High and mid-level clouds often masked the area and even though there were many techniques to identify low clouds it wasn’t always possible to determine if they were elevated or touching the ground. This created a need for different categories that described each scene, in addition to just fog or no fog. Also, time constraints limited the number of satellite images that were analyzed and ultimately the size of the data set.

B. RELATED BACKGROUND INFORMATION

1. Satellite Fog Detection

Fog climatology studies for remote locations have been difficult tasks. Observations over land are routinely taken at weather stations but accurate detection is usually limited to the daytime and only in the immediate vicinity of the station. Conditions are worse over the sea; reports come from ships, buoys, or lighthouses with a significant drop in frequency and accuracy (Ahn et al. 2003). For fog detection extending to large areas, at nighttime, and over remote locations, satellite imagery is the best solution but there are also inherent problems with this approach. The techniques used in fog detection from previous studies were reviewed and discussed below, along with the issues they faced.

The detection of low stratus or fog from satellites has distinct challenges, and it was even more difficult to distinguish between the two. Part (a) of this section discusses problems with fog detection inherent in all satellite images, Parts (b) and (c) cover methods that accurately identify low clouds for daytime and nighttime images respectively. During the identification process (Parts a and b) the terms fog and low cloud are used interchangeably since the distinction between the two isn't made here. Part d tackles the issue of fog versus stratus. Fog detection was separated into two categories, daytime and nighttime, because daytime imagery has the advantage of visible bands to assist in the identification.

a. Common Detection Problems

There are times when fog detection from satellite imagery is almost impossible no matter what techniques are used. The most common example occurs when a solid layer of high or mid-level cloud masks the surface. Any lower clouds present could only be observed through continuous coverage and an eventual break in the higher clouds (Ellrod 1995). Other issues seen in this current satellite study were in spatial and temporal resolution. Small areas of fog weren't resolved by the satellite and thin layers

didn't provide a sufficient radiance contrast with the surrounding background to be detected. Due to the short duration of some fogs and lack of continuous coverage, certain events would go undetected by either satellite. For example in our study the Terra MODIS passed over Korea around 0130 UTC (1030 local time) and about 1330 UTC (2230 local time). Fog events were often reported by surface observations between the two passes, but never identified on the satellite images.

b. Nighttime Detection

Fog was difficult to detect at night because of the absence of the visible channels and the low thermal contrast between the fog and surrounding clear areas (Ahn et al. 2003). The meteorological satellite infrared (IR) sensors detected the total radiance of the scene which was the combination of the radiance of the cloud, any transmitted radiance from below the cloud, and the path radiance above the cloud. If the total radiance for a viewing area was similar to the surrounding environment then the sensor couldn't distinguish between cloud and background (Ernst 1975). For this reason, nighttime detection required a different approach (see Figure 2). The dual channel difference (DCD) method was used, which had been successful for many years. It utilized the different optical responses to fog by two channels (Ahn et al. 2003). MODIS channel 22 (3.929-3.989 µm) in the near infrared (NIR) range had a lower emissivity for fog than the MODIS IR channel 31 (10.78-11.28 µm), which was emitted at near blackbody level or close to one by the fog (Eyre et al, 1984). The difference in emissivity was generally 20-40% for significant cloud depths (Ellrod 1995). There were also transmissivity variations in the two channels that allowed NIR wavelengths to come from lower in the cloud. Since the cloud was normally sitting within an inversion, the emissivity and transmissivity differences contributed to a lower brightness temperature for Channel 22. This lower value was most pronounced in clouds with small droplets like fog. When the brightness temperature of channel 22 was subtracted from that of channel 31, the result was a positive value which was visually enhanced to identify the fog (see Figure 3). Ice clouds like cirrus had a reversed difference value due to the increased transmissivity of channel 22. In clear air the difference was much smaller and was due

mainly to variations in water vapor absorption between the two channels (Ellrod 1995). The DCD method also worked to distinguish fog from snow covered ground at night since snow also emitted the 3.9 µm NIR wavelength more efficiently than fog just like a clear surface or sea.

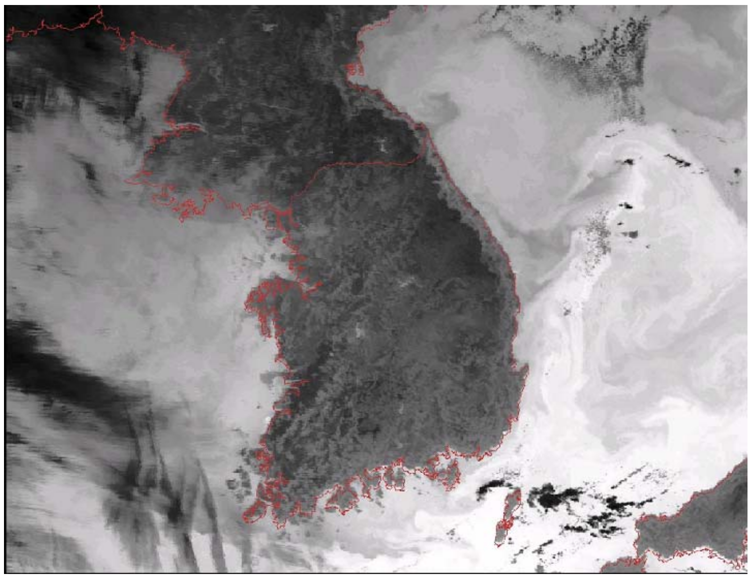


Figure 2. A nighttime infrared image of Korea from MODIS Channel 31, from 1705 UTC October 26, 2005. This image shows the difficulty in detecting fog.

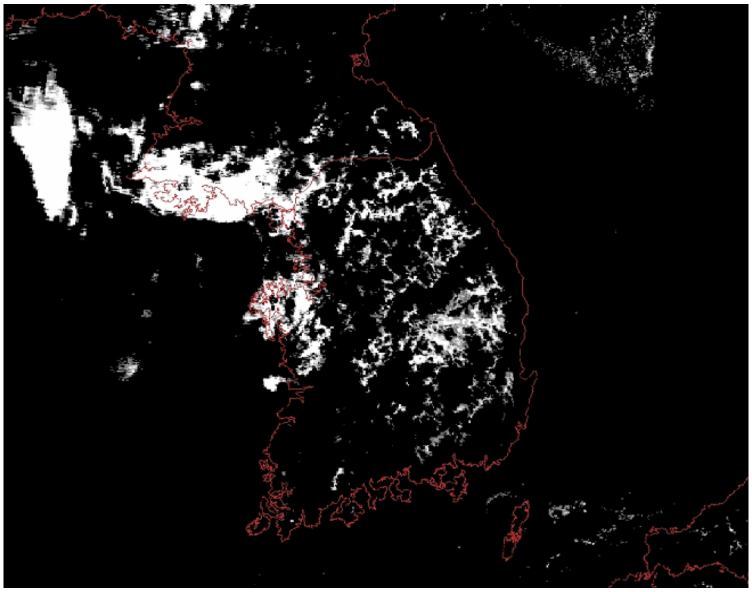


Figure 3. Dual Channel Difference (DCD) enhanced image for nighttime fog detection. The difference in radiance between MODIS Channels 31 and 22 are shown from 1705 UTC October 26, 2005 to illustrate the improved fog detection capability.

The DCD method was very versatile to the types of terrain and surface temperatures over which it detected fog, but it wasn't without flaws. There were a few instances when this method had problems in previous studies and produced false alarms. If the surface temperature was much less than 0˚C there was an increase in instrument noise but unless it went below -20˚C the fog signal was strong enough to be observed. This typically didn't occur on the Korean peninsula. Occasionally certain types of soil produced the same difference signal as fog and resulted in a false reading. This was identified through repeated occurrences but again wasn't a problem for Korea. Higher based stratiform clouds such as stratocumulus or altocumulus often produced a positive DCD value and resemble fog on an enhanced view but through further interrogation of texture differences and brightness temperatures with channel 31, they were easily discarded as elevated cloud (Ellrod 1995).

c. Daytime Detection

Daytime fog detection in most cases was more straight-forward than nighttime. It was previously shown that areas of fog were very bright in the visible image since water clouds strongly reflected solar radiation at visible wavelengths. Unlike other clouds, fog was relatively warm in the infrared image since its temperature was close to that of the underlying surface (Eyre et al. 1984). Through the use of these distinct characteristics and with the combined visible and infrared information it was easy to distinguish between fog and other clouds. The DCD method used in nighttime detection provided much less utility during the day. The total observed radiance in the NIR channel 22 was dominated by reflected solar radiation which contaminated the 31-22 difference value. The increased brightness temperature for channel 22 was so significant, that it gave a negative DCD value. This result was still different from higher ice containing clouds, but it wasn't useful in distinguishing fog from other water clouds (Ellrod 1995).

The NIR images were still very useful during the day for distinguishing fog from snow. The solar reflectance off snow was much smaller than fog in the NIR. This difference resulted in an extreme irradiance contrast between fog and snow cover which was easily enhanced to isolate the two (Ellrod 1995; Allen et al. 1989) as shown in Figures 4 and 5. Once again, the methods mentioned here were very effective in distinguishing low clouds from mid and upper level clouds, but the problem still existed in determining if the low clouds were actually on the ground.

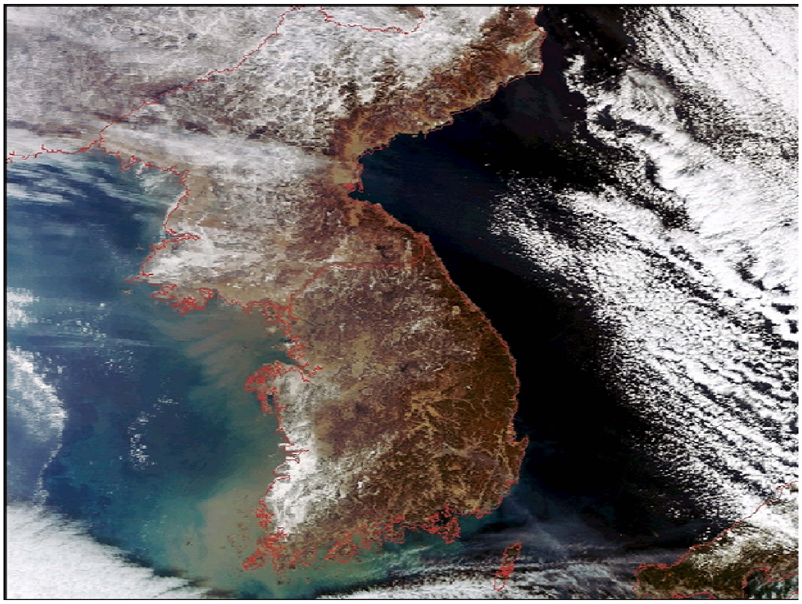


Figure 4. A daytime visible MODIS image of Korea from 0205 UTC January 3, 2006. Areas of possible snow and fog are evident in this image.

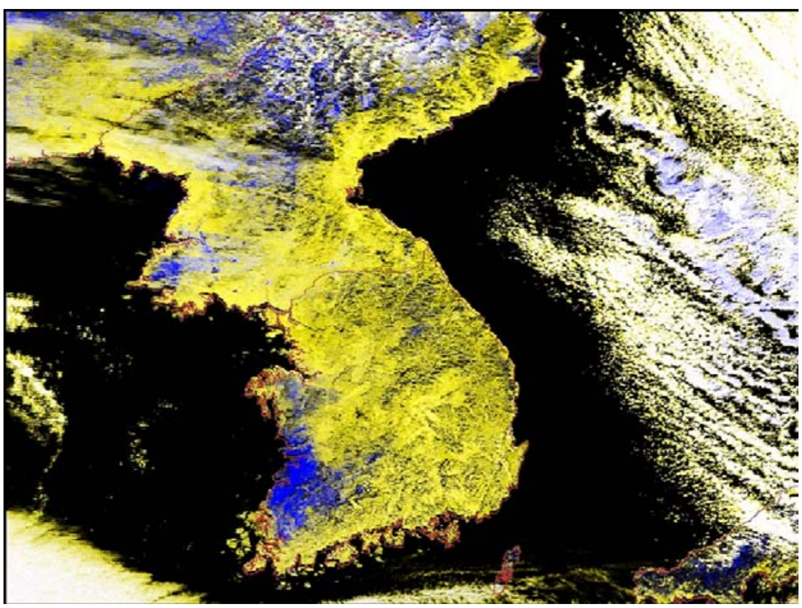


Figure 5. A snow enhanced image of Korea using MODIS Channels 2 and 7 from 0205 UTC January 3, 2006 showing the ability to distinguish between snow and fog with daytime images.

d. Fog or Cloud Distinction

Some visual characteristics of fog gave an indication that it was actually on the ground such as flat texture, sharp edges, and patterns that conformed to topographical features like river beds or mountain valleys (Anderson et al. 1974). Also, temperature differences between the cloud top and surrounding land or sea surface provided some clue in determining if the low cloud was fog or elevated stratus. Elevated cloud usually had a greater difference in brightness temperature with the surface however, this wasn't always the case. It was dependant on the temperature profile and the depth of the fog. The best way to decide if the fog was actually on the ground was through the use of any surface observations or soundings that were available in the area.

2. Previous Climatology Data Sets for Korea

There were a few attempts at creating fog climatology data sets for Korea in the past. Three of the studies were reviewed and discussed in this section. All three used archived surface observations to create the data sets. The tables of data from each study were adapted to fit the nine areas of interest in this study and were placed in Appendix 2. The results of this study were compared with the three earlier data sets in the Summary of Results Section.

a. Kim and Lee Study

The first climatology study for Korea was completed by Kim and Lee (1970). It examined monthly mean fog days, fog duration, and fog-occurrence-time. The mean fog days were similar to results from this study. They were based on 30 years of surface observations from 1931 to 1960 at land stations in South Korea. The North Korea data was produced from 50 years of the Climatology Charts of Meteorology for Korea, but the accuracy was considered questionable by some meteorologists. The Kim and Lee (1970) study created a worksheet with the number of mean fog days per month for each station and produced maps for each month with isopleths that outlined the mean days of fog across the peninsula. They used the data to separate the peninsula into different categories based on the frequency of fog per month and season. These regions

did not match up well with the areas of interest from this satellite study but the individual station information from the worksheet was easily assigned to one of the areas for a results comparison.

b. U.S. Navy's Study

The United States Navy completed a vast study in 1971 titled Study of Worldwide Occurrence of Fog, Thunderstorms, Supercooled Low Clouds and Freezing Temperatures (Guttman 1978) and then later published an update (Change 1) to this report in 1978. Similar to the Kim and Lee (1970) study this report provided monthly world maps with isopleths identifying the number of fog days in the marine areas. They used more extensive data from 1854 to 1974 in the North Pacific. The data source was Tape Data Family-11, Surface Marine Observations, on file at the National Climatic Center. This data included "observations from ship logs, ship weather reporting forms, published ship observations, automatic data buoys, teletype reports, and on cards purchased from several foreign meteorological services. The quality of instruments ranges from those found aboard a 19th century whaling ship to the most sophisticated electronic equipment used on ocean weather ships. Observer qualifications vary from deck hand to trained meteorologist," (Guttman 1978).

The report also used land observations from the National Climatic Center's Synoptic Data File (Tape Deck 9685) covering the period 1966 to 1975. They produced a table of fog occurrences for weather stations across the Korean Peninsula. The table included four observation times; 00, 06, 12, and 18 UTC for each of the four mid season months; January, April, July, and October. The observers used the World Meteorological Organization (WMO) past and present weather codes 4, 10, 11, 12, 28, and 40-49 to identify fog. The tables were then broken down into four parts A, B, C, and D where: PART "A" was derived using present weather codes 10, 11, 12, 28, 40-49, plus past weather code 4. PART "B" was derived using present weather codes 10, 11, 12, 28, and 40-49. PART "C" was derived using present weather codes 40-49. PART "D" was derived using present weather codes 40-49, plus past weather code 4.

Each station had to meet a selection criterion before their data was used. They had at least six years of observations for each synoptic hour and at least 20 observations for each hour per month. An exception was made for some stations that only reported during the three daylight observation hours to ensure a wide aerial coverage. Part A of this database (all fog occurrences) included information similar to this satellite study and was used for comparisons.

c. AFCCC Data Set

The Air Force Combat Climatology Center (AFCCC) produced many products that were useful for this fog study including; surface observation and upper air summaries; monthly, seasonal, and annual narrative briefs; and numerous climatology maps. Like the previous studies AFCCC produced both, point location maps from historical station data and also shaded contour maps that have interpolated data to provide coverage between stations. The period of observations varied greatly between stations. In North Korea the beginning period started as early as 1950 and as late as 1976 while the ending period ranged from 1996 to 2005. There was a similar pattern for South Korea; most stations had beginning observations from the 1950s or 1970s with some newer locations that began in the late 1980s or early 1990s. The ending periods once again went from the late 1990s up to 2006 (AFCCC 2007). Upon request AFCCC produced the monthly mean fog days for each station in a spreadsheet instead of map form for easier adaptation. This data came from the Operational Climatic Data Summary (OCDS) for each station and was divided into the appropriate areas of interest from this study.

AFCCC also produced modeled climatology from there Advanced Climate Modeling and Environmental Simulations (ACMES) program which utilized the Meso-scale Atmospheric Simulation System (MASS) model. The maps were produced from the model analysis data and the climatology period was from October 1986 to September 1996. They were also able to generate other specific runs as needed.

3. Types of Fog and Fog Formation Mechanisms

For this study fog was defined as any cloud touching the surface, which was close to the definition from Glickman (2000), "water droplets, suspended in the atmosphere in the vicinity of the earth's surface, that affect visibility." Before completing this fog study, it was important to identify the types of fog involved. There were two types of fog formation that occurred around the Korean peninsula; sea fog and land fog. Without continuous satellite coverage it was impossible to know what had caused the fog formation in a given image, so fog was separated into two distinguishable types to provide more detail for the data set. Fog seen along the coast which included a body of fog that extended inland a short distance was considered "coastal fog." Fog that was separated from the coast, i.e., not part of a continuous body of fog that reached the coastline, was called "inland fog." It was important to consider all possible scenarios that could have contributed to the development of each fog type before a thorough analysis of the results was completed. The fogs in the satellite images could have developed from land fog that formed in the area, or advected in from another location; sea fog that advected on shore; or a combination of the two. So, conditions leading to sea fog and land fog were investigated.

For any fog formation, supersaturation of the air had to occur. Roach (1994) and Binhua (1985) discussed the two methods for reaching supersaturation. Either the air temperature was cooled, the water vapor increased, or some combination of the two occurred. It was shown; cooling either resulted from radiative loss, adiabatic lifting, or advection, while evaporation produced the increased water vapor. Another method occurred when two air parcels near saturation with different temperatures were combined; the mixed air became supersaturated. Figure 6 from Roach (1994) summarized the theory behind this process.

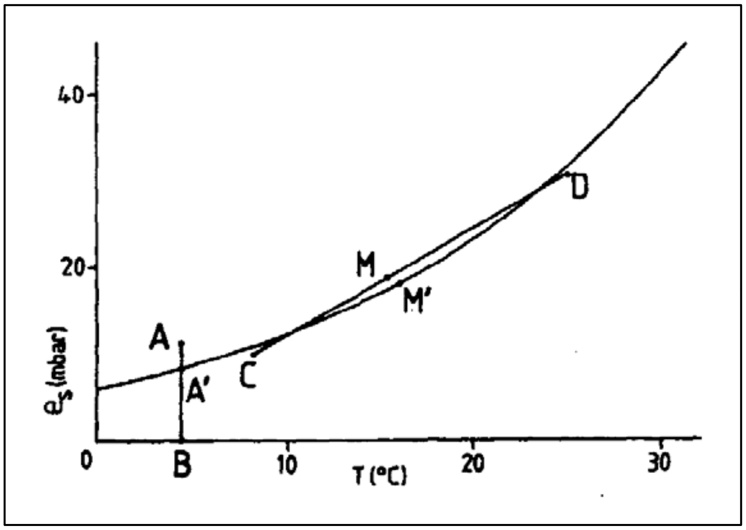


Figure 6. Saturation water vapor pressure, e_s, as a function of temperature, T. It shows how two air parcels, C and D, can mix to create a supersaturated parcel, M.

a. Land Fog

Land fog was divided into four categories; hill fog, radiation fog, advection fog, and coastal fog (Roach 1995a). Coastal fog was described as sea fog that advected inland which fell under Part b. Hill fog developed from clouds that lowered to the surface, typically over hills or elevated terrain. Advection fog occurred when warm moist air moved over a cooler surface, such as snow. The warm air was cooled to the point of saturation and condensation occurred which created the fog. Another type of advection fog was identified by Roach (1995a) as large bodies of fog that were advected over motorways or other locations. Radiation fog, the most common land fog was explained in depth by Roach (1995a). Radiative cooling from the surface drove the initial formation, this implied clear skies which allowed the radiation to escape and stable conditions for an inversion to develop near the surface. As the ground cooled a temperature gradient developed between the surface and air above. When the surface reached the dew point temperature, the lowest layer of air deposited excess water vapor as dew on the surface until the inversion was formed. The inversion stopped the turbulent transfer of moisture between the two layers. The layer of air continued to cool

radiatively with no where to deposit the excess water vapor so it condensed into fog droplets. The inversion at the surface eroded away as conduction from within the soil continued to warm the surface and radiative heat loss was cut off by the fog layer. The fog droplets continued to radiate heat which strengthened the fog top inversion and deepened the fog layer. Turbulent eddies mixed the lowest layers which brought fog down to the surface but also improved visibilities near the ground slightly (Roach 1995a).

b. Sea Fog

Roach (1995b) indicated there were three possible mechanisms that occurred when sea fog developed. There was a stark contrast in air sea temperatures in either direction (air colder or warmer than the sea) or elevated clouds were lowered to the surface through dynamic processes. The first two were both considered types of advection fog. When warm air advected over cooler water and cooled to the point of saturation it was called advection cooling fog. Fog formed when cooler air moved over warm water was labeled advection evaporation fog (Binhua 1985) because water vapor was transferred from the sea to the cooler air by evaporation. The increase in water vapor caused saturation of the air and fog droplets formed. The transfer of water vapor to the air continued due to the remaining moisture gradient with the sea surface which caused the fog to deepen. Sea fog has also developed from stratus lowering to the surface (Koracin et al. 2000). The primary factors that caused lowering of the stratus layer were cloud top cooling and increased subsidence. The cloud top cooling caused instability and turbulent mixing of moisture in the marine layer while increased subsidence lowered the boundary layer and forced the cloud bases to the surface.

Cho et al. (2000) and Lewis (2004) identified advective cooling fog as the primary source of sea fog around the Korean peninsula. Sea fog was seen year round with a maximum occurrence in the summer. This was explained by the change in sea currents shown in Figure 7. The summertime current in the west sea reversed to a northerly flow along the west coast and eventually developed a closed circulation which caused upwelling of cooler water. This upwelling created the temperature gradient

needed for the advective cooling process. All other types of sea fog have likely occurred around Korea but the limited studies for the region have not identified them.

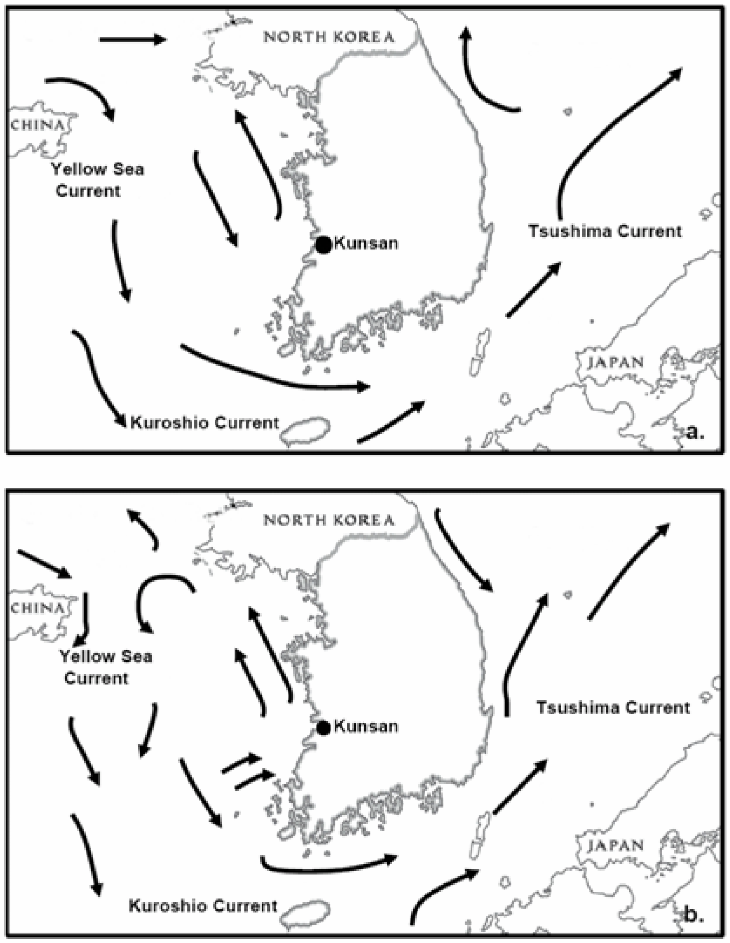


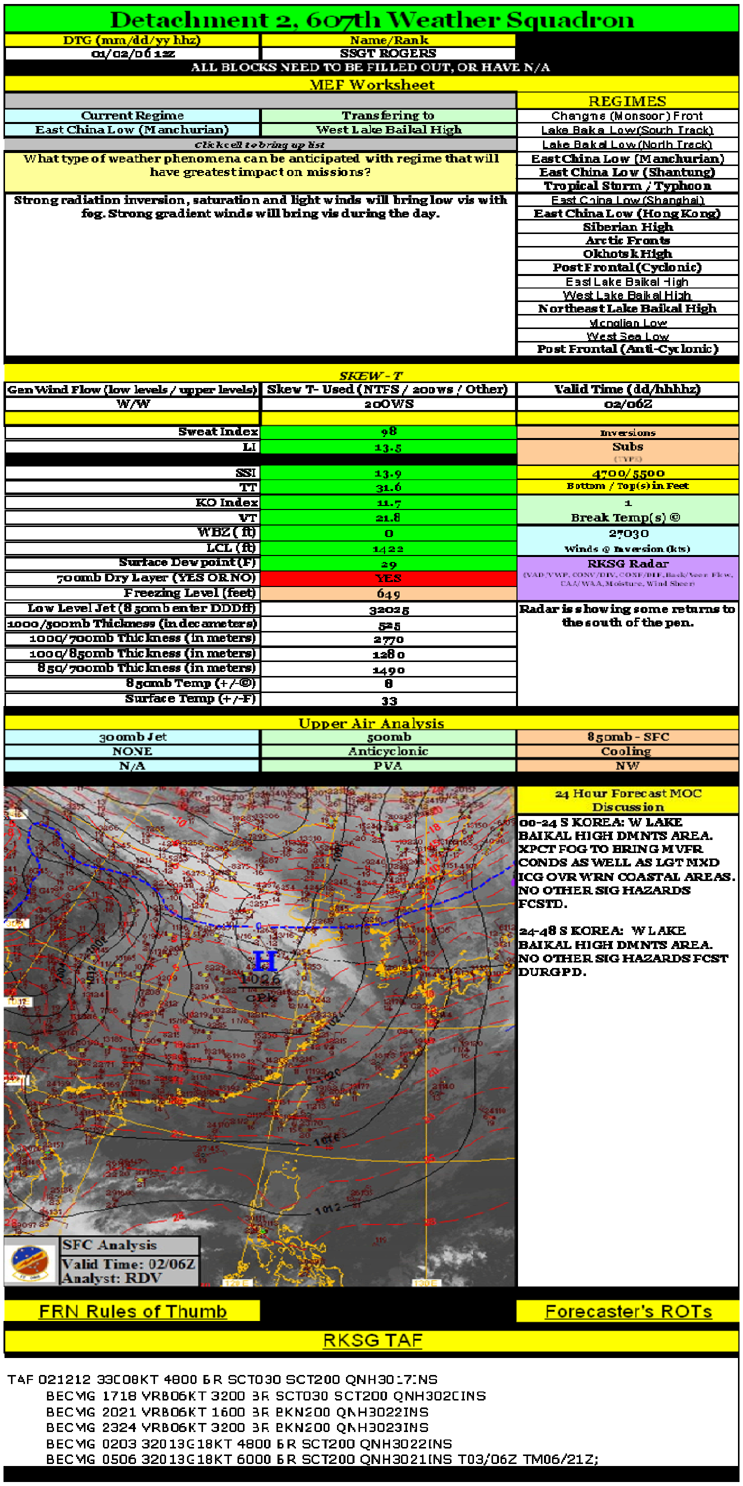
Figure 7. A schematic of ocean currents surrounding the Korean Peninsula for (a) Winter and (b) Summer seasons (from Lewis 2004).

II. PROCEDURES

A. DATA COLLECTION

The first step was to identify the available data sources and obtain the data needed to complete this study. The data sources that were explored include satellite images, surface observations, upper-air soundings, forecast worksheets, earlier climatology reports, and mesoscale model results.

The 607 Weather Squadron provided the forecast worksheets (see an example in Figure 8), which were excel spreadsheets formatted as a guideline used by forecasters when preparing their terminal aerodrome forecast (TAF). The archived set was for Camp Humphreys, ROK and included 13 months of data from July 2005 through July 2006. This established the timeline for the study. They included analysis and forecasts discussions, synoptic pattern or regime descriptions, a synoptic analysis chart with satellite overlay, and a copy of the TAF for the period. There were three worksheets per day at 4, 12, and 20 UTC; one for each TAF produced.



Detachment 2, 607th Weather Squadron

DTG (mm/dd/yy hhz)	Name/Rank	
01/02/06 12Z	SSGT ROGERS	

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MEF Worksheet

Current Regime	Transfering to	REGIMES
East China Low (Manchurian)	West Lake Baikal High	Changma (Monsoon) Front
Click cell to bring up list		Lake Baikal Low (South Track)
What type of weather phenomena can be anticipated with regime that will have greatest impact on missions?		Lake Baikal Low (North Track)
Strong radiation inversion, saturation and light winds will bring low vis with fog. Strong gradient winds will bring vis during the day.		East China Low (Manchurian)
		East China Low (Shantung)
		Tropical Storm / Typhoon
		East China Low (Shanghai)
		East China Low (Hong Kong)
		Siberian High
		Arctic Fronts
		Okhotsk High
		Post Frontal (Cyclonic)
		East Lake Baikal High
		West Lake Baikal High
		Northeast Lake Baikal High
		Mongolian Low
		West Sea Low
		Post Frontal (Anti-Cyclonic)

SKEW - T

Gen Wind Flow (low levels / upper levels)	Skew T- Used (NTFS / 200ws / Other)	Valid Time (dd/hhhhz)
W/W	200WS	02/06Z
Sweat Index	98	Inversions
LI	13.5	Subs (TYPE)
SSI	13.9	4700/5500
TT	31.6	Bottom / Top(s) in Feet
KO Index	11.7	1
VT	21.8	Break Temp(s) ©
WBZ (ft)	0	27030
LCL (ft)	1422	Winds @ Inversion (kts)
Surface Dewpoint (F)	29	RKSG Radar (VAD/VWP, CONV/DIV, CONF/DIF, Back/Veer Flow, CAA/WAA, Moisture, Wind Shear)
700mb Dry Layer (YES OR NO)	YES	
Freezing Level (feet)	649	
Low Level Jet (850mb enter DDDff)	32025	Radar is showing some returns to the south of the pen.
1000/500mb Thickness (in decameters)	525	
1000/700mb Thickness (in meters)	2770	
1000/850mb Thickness (in meters)	1280	
850/700mb Thickness (in meters)	1490	
850mb Temp (+/-©)	8	
Surface Temp (+/-F)	33	

Upper Air Analysis

300mb Jet	500mb	850mb - SFC
NONE	Anticyclonic	Cooling
N/A	PVA	NW

24 Hour Forecast MOC Discussion

00-24 S KOREA: W LAKE BAIKAL HIGH DMNTS AREA. XPCT FOG TO BRING MVFR CONDS AS WELL AS LGT MXD ICG OVR WRN COASTAL AREAS. NO OTHER SIG HAZARDS FCSTD.

24-48 S KOREA: W LAKE BAIKAL HIGH DMNTS AREA. NO OTHER SIG HAZARDS FCST DURGPD.

FRN Rules of Thumb

Forecaster's ROTs

RKSG TAF

```
TAF 021212 33008KT 4800 BR SCT030 SCT200 QNH3017INS
      BECMG 1718 VRB06KT 3200 BR SCT030 SCT200 QNH3020INS
      BECMG 2021 VRB06KT 1600 BR BKN200 QNH3022INS
      BECMG 2324 VRB06KT 3200 BR BKN200 QNH3023INS
      BECMG 0203 32013G18KT 4800 BR SCT200 QNH3022INS
      BECMG 0506 32013G18KT 6000 BR SCT200 QNH3021INS T03/06Z TM06/21Z;
```

Figure 8. An example of the forecasts worksheets used by forecasters attached to the 607th Weather Squadron, Korea.

For this study, AFCCC had a wealth of products available for use. They provided archived surface observations and upper air soundings for the entire year for a central location, Camp Humphreys. AFCCC also sent other surface observations from many stations across South Korea and one in North Korea for the four months chosen for the analysis. These additional observations helped confirm when fog was on the ground. Figure 9 indicated the coverage they provided across the peninsula. The lack of observations in North Korea was a problem and the methods used to work around it are described later in this section. AFCCC (2007), offered general climatology briefs for many specific Korean stations and had several maps available with climatology data for observation sites across the peninsula as discussed in Chapter I. Finally, AFCCC provided model data from their Mesoscale Atmospheric Simulation System (MASS) model. As a result of this study, a four day period in October 2005 was chosen that had considerable fog coverage over Korea clearly identified by satellite imagery. Upon request, AFCCC ran the MASS model for these four days and provided the three-hourly raw output data at 10 km horizontal resolution with 20 sigma layers over the Korean peninsula. The model was run in 12 hour increments with re-initializations at 00 and 12 GMT using the previous model run as a first-guess field. Profiles of cloud water, temperature, potential temperature, water vapor mixing ratio, and the horizontal wind components were created from the model output to use as a possible fog analysis tool. An example of the profiles is shown in Figure 10.

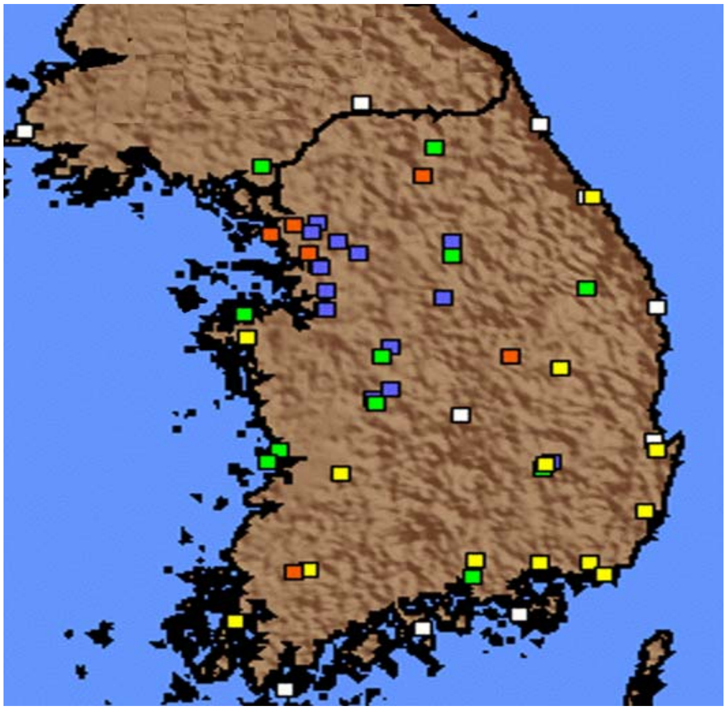

Figure 9. A map of Korea indicating the approximate locations of the surface observations provided by the Air Force Combat Climatology Center (after AFCCC 2007).

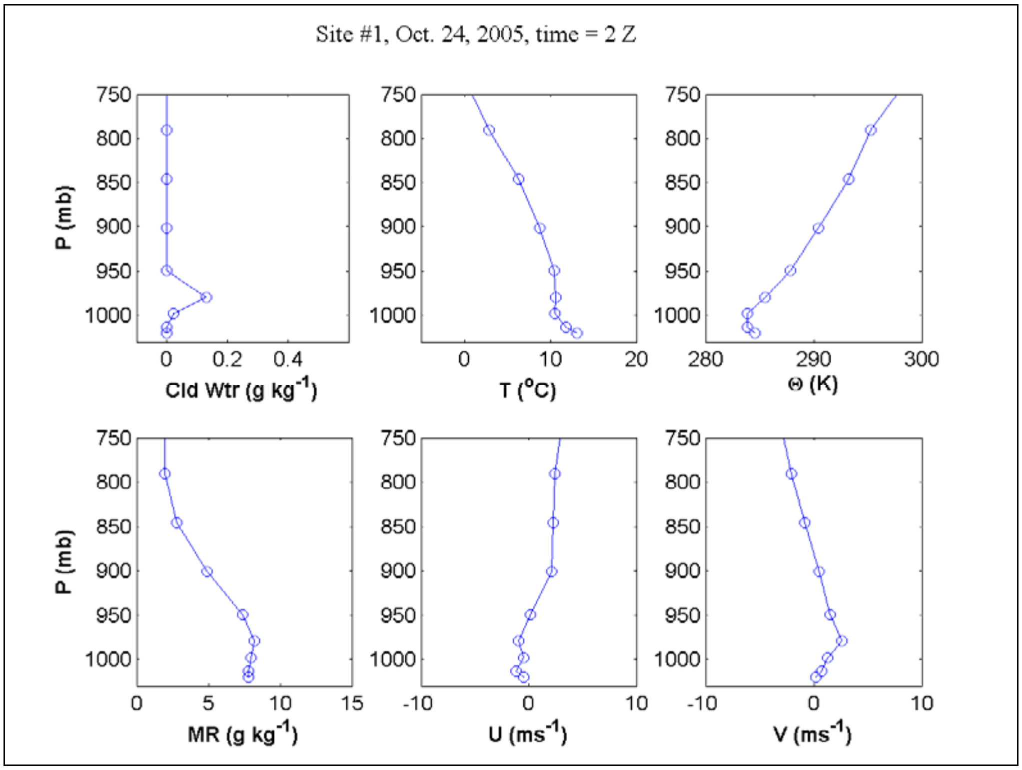

Figure 10. Example of the profiles created from model output provided by AFCCCs Mesoscale Atmospheric Simulation System (MASS) model. The upper panels show the cloud water content, temperature, and potential temperature; the lower panels show the water vapor mixing ratio and the north-south and east-west horizontal wind components.

There were no high resolution geostationary images archived for the period covered in this study (October 2005 through July 2006), so the satellite imagery came from NASA (2007b). They were ordered from the Goddard Space Flight Center website called LAADS Web which stands for Level 1 and Atmosphere Archive and Distribution System. This website provided archived Moderate-Resolution Imaging Spectroradiometer (MODIS) data. The images were selected by choosing a day/time range and an area outlined by longitude/latitude boundaries. The MODIS images came from the Terra and Aqua satellites formerly known as EOS AM-1 and EOS PM-1, which are part of the Earth Observing System (EOS) series. Both satellites were sun-synchronous, near-polar orbiters, flying at an altitude of about 705 km. The Terra satellite follows a descending morning track, crossing the equator at approximately 1030

UTC, while the Aqua compliments the Terra with an ascending afternoon track, crossing the equator around 1330 UTC. The two satellites view the entire globe every 1-2 days. The MODIS instruments have a swath width of 2330 km and provided imagery in 36 discrete bands from 0.4 to 14.5 µm. The spatial resolution includes 250 m for bands one and two (red and NIR), 500 m for bands three through seven, and 1000 m for bands eight through 36. The bands used were highlighted in Table 1. For this study, the visible bands for daytime imagery were used, and channels 31 and 32 were used for infrared temperature information. The near infrared channels were analyzed for low cloud and snow enhancement. Band 22 (3.939 – 3.989 µm) was used to depict low clouds at night and band 7 (2.105 – 2.155 µm) was for distinguishing snow from low cloud during the daytime. Band 6 (1.628 – 1.652 µm) was preferred for snow depiction however this band failed on the Aqua satellite shortly after launch so band 7 was used as a substitute (NASA 2007a).

Table 1. A list of the bands available with the Moderate-Resolution Imaging Spectroradiometer (MODIS) system used by the Aqua and Terra satellites. The highlighted bands were used in this study.

Aggregated 250 m	*Aggregated 500 m*	*1 km*	*1 km*
Band 1 (620-670 nm)	**Band 3 (459-479 nm)**	Band 8 (405-420 nm)	Band 20 (3.660-3.840 μm)
Band 2 (841-876 nm)	**Band 4 (545-565 nm)**	Band 9 (438-448 nm)	Band 21 (3.929-3.989 μm)
	Band 5 (1230-1250 nm)	Band 10 (483-493 nm)	**Band 22 (3.939-3.989 μm)**
	Band 6 (1628-1652 nm)	Band 11 (526-536 nm)	Band 23 (4.020-4.080 μm)
	Band 7 (2105-2155 nm)	Band 12 (546-556 nm)	Band 24 (4.433-4.498 μm)
		Band 13L (662-672 nm)	Band 25 (4.482-4.549 μm)
		Band 13H (662-672 nm)	Band 27 (6.535-6.895 μm)
		Band 14L (673-683 nm)	Band 28 (7.175-7.475 μm)
		Band 14H (673-683 nm)	Band 29 (8.400-8.700 μm)
		Band 15 (743-753 nm)	Band 30 (9.580-9.880 μm)
		Band 16 (862-877 nm)	**Band 31 (10.780-11.280 μm)**
		Band 17 (890-920 nm)	**Band 32 (11.770-12.270 μm)**
		Band 18 (931-941 nm)	Band 33 (13.185-13.485 μm)
		Band 19 (915-965 nm)	Band 34 (13.485-13.785 μm)
		Band 26 (1.360-1.390 μm)	Band 35 (13.785-14.085 μm)
			Band 36 (14.085-14.385 μm)

Once the images from NASA (2007b) arrived the format was changed from raw radiance measurements to the TeraScan Data Format (TDF) so that they could be viewed and manipulated by TeraVision software. This enabled the viewing of each channel available in MODIS. TeraVision's built-in tools allowed for image enhancements and multiple channel combinations or differences to create enhanced views of the imagery. Examples of this were the Dual Channel Difference method for identifying low clouds at night or combining Channel 7 with one of the visible bands to create a snow enhancement as discussed in Section two. The TeraVision software also provided

geographical overlays and latitude/longitude positions. So, not only was it possible to view the standard visible and infrared images but also use common techniques to isolate certain objects like cirrus clouds, fog, and snow. The mouse-driven survey tool gave simultaneously measured data values for all channels at any location on the image. The survey tool gave irradiance values for the visible bands and brightness temperatures for the IR channels, very helpful in estimating the height of a cloud in the atmosphere and the approximate temperature of the surface. Once the tool set was complete, techniques for identifying fog were needed to start creating a climatology database.

B. CREATING CLIMATOLOGY DATABASE

The strategy for this study was to use satellite imagery to determine if and when fog was present over remote locations or "choke points", as requested by the 607 WS. Due to personnel turnover these locations could not be identified, so instead Korea was divided into 9 different areas based partly on geographical features and also by political interests. There were two areas in North Korea and two along the demilitarized zone (DMZ). The remaining areas were spread out over South Korea along the coastal regions and inner mountain locations. The areas were numbered in order of interest as determined by the 607 WS (see Figure 11). Within these areas it was determined to a certain degree if there was fog or not for each satellite image. To a certain degree meaning the answer was not always clear. So, categories were defined for each scene based on the ability to determine if fog was present.

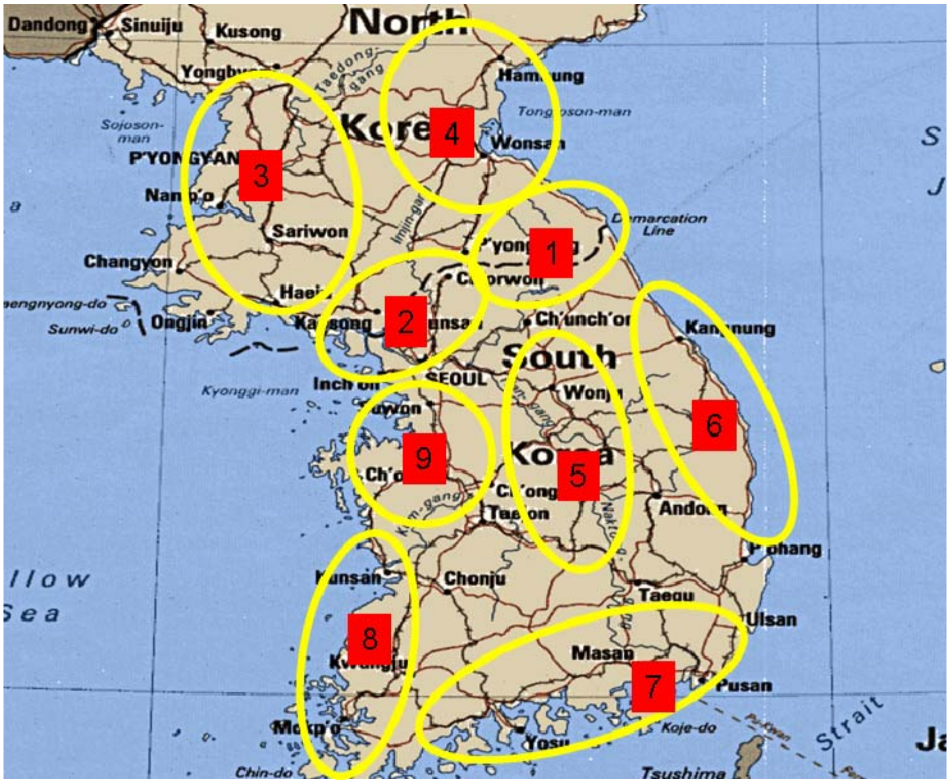

Figure 11. A map of Korea separated into areas of interest for this study based on geographical differences and political interests. The areas were numbered in order of importance as viewed by the 607th Weather Squadron.

1. Fog Categories

The categories were numbered one through seven and were named: fog, fog likely, fog possible, fog unlikely, no fog, covered by higher cloud, mostly covered by higher cloud with no fog seen in breaks. Category one, fog, was further broken down into three parts (1- fog inland, 1.1- coastal fog, and 1.2- both coastal and inland fog), to give some additional insight into the type of fog that was present (see Table 2). The names of the categories were simple to understand but it was critical to determine how they related to given scenarios and what thresholds would separate each category. The best way to define each category was through specific examples starting with the easiest decisions first. For category five, "no fog", if the area was free of any clouds that could

be resolved by the satellite then it was considered to have no fog present. The subjective part developed when a few high clouds were present; what percent coverage would cause a change in category? It depended on the situation but a rule-of-thumb was, less than ten percent coverage resulted in no fog. Category six, "covered by higher cloud", was generally easy to determine; when an area was completely covered by cloud and the brightness temperature indicated they were in the mid to upper-levels, then it became classified as category six. There were cases when the choice wasn't so unambiguous. When the cloud coverage was less than 100 percent and no fog was seen in the openings, a decision had to be made between the other possible categories. Again, it was case dependant but a standard rule could be made for greater than 90 percent coverage equating to a category six. Another subjective decision had to be made when the cloud coverage occurred closer to the ground. This proved to be a difficult situation and not easy to generalize. They were handled carefully on an individual basis with the use of surface observations and upper air soundings. A good starting point was to consider a cloud-surface temperature difference of more than ten degrees to be a category six and less than ten degrees to at least be possible for fog, pending further interrogation. The final less difficult category was seven, it was very similar to six in that an area experienced a majority of cloud coverage and no fog was seen in the openings. The only difference was the percentage of cloud cover; an area generally had 60 to 90 percent coverage before it earned a category seven. Categories three and four were used sparsely and only when more distinct choices couldn't be reached. When an area had 10 to 50 percent coverage from elevated clouds and no fog was seen in the open regions, one of these categories was often used depending on other supporting evidence. If the clouds were close to the surface, fog was seen in other areas, or conditions were favorable for fog then category three was used to declare fog was possible. If on the other hand no indications of fog were present then category four was used, saying that fog was unlikely to be present. This was evident on a few warm spring and summer days when the convective temperature had already been reached and cumulus and other convective clouds filled much of the image. There was no sign of fog in the area due to the convective nature of the atmosphere. Three was also used when areas with few or no

additional data sources like surface observations, experienced low clouds but, had a cloud-surface temperature difference too great to be placed in category two, “fog likely.” Normally, low clouds had to be identified and the cloud-surface temperature difference was about five degrees or fewer, for an area to receive a category two. There were just not enough additional indications or data that would confirm the clouds were on the surface. Category one required more information that supported the brightness temperature test. Surface observations were the most trusted but in areas where additional data was absent, visual indications, like clouds conforming to the topography were sufficient. Also, if the same patch of sea fog extended up the coast or inland from a confirmed fog location with similar terrain, the evidence was sufficient to warrant a category one. After fog was determined to be on the ground, it was identified as coastal fog (1.1), inland fog (1), or both types (1.2). From Chapter 1, coastal fog was determined to be any fog touching the coast and included connected fog that extended inland from the coast; conversely, inland fog was separated from the coast and was normally trapped in valleys or low lying areas. Often times, areas that were connected to a sea would experience both types of fog and were designated with a category 1.2. Now that the different categories were established it was time to develop techniques for identifying each one.

Table 2. List of the fog categories with descriptions, needed to describe all possible scenes identified using satellite images as a primary data source.

Categories	Descriptions
1 = Fog Inland	Fog Present and Separated from the Coast
1.1 = Coastal Fog	Fog on Coast or Extending Inland a Short Distance
1.2 = Coastal and Inland Fog	Both Types of Fog Found in Same Area
2 = Fog Likely	Brightness Temps Suggest Fog but Could Not Confirm
3 = Fog Possible	Low Cloud But Evidence Not as Strong as Fog Likely
4 = Fog Unlikely	Partially Covered and Conditions not Favorable for Fog
5 = No Fog	No Clouds Detected
6 = Covered by Higher Cloud	Could Not See Below an Elevated Layer of Cloud
7 = Mostly Covered by Higher Cloud	Some Breaks in the Clouds but no Low Clouds Detected
ND = No Data Available	Satellite Image was Missing

2. Identification Techniques

Using all of the information gathered from previous satellite and fog studies, a strategy was developed for identifying the appropriate fog category for each image with the data available. Two separate techniques were needed, one for daytime and one for nighttime fog detection. A decision tree was created for each approach (see Figures 13 and 14). The decision trees give the ability to systematically step through an image and make decisions but are ambiguous or flexible enough to adapt to any scenario.

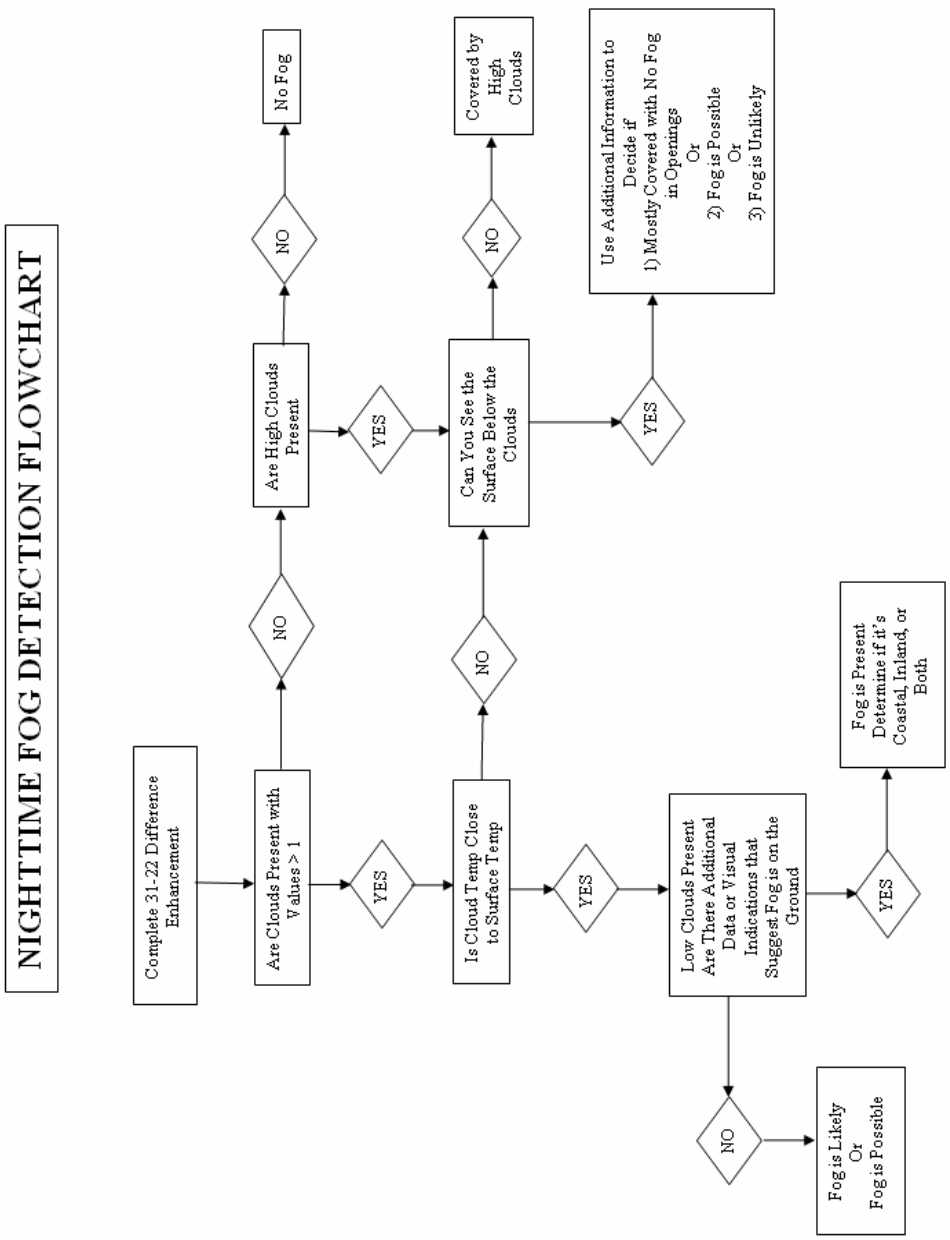

Figure 12. A decision tree identifying the steps used to detect fog at night with satellite imagery as the primary tool.

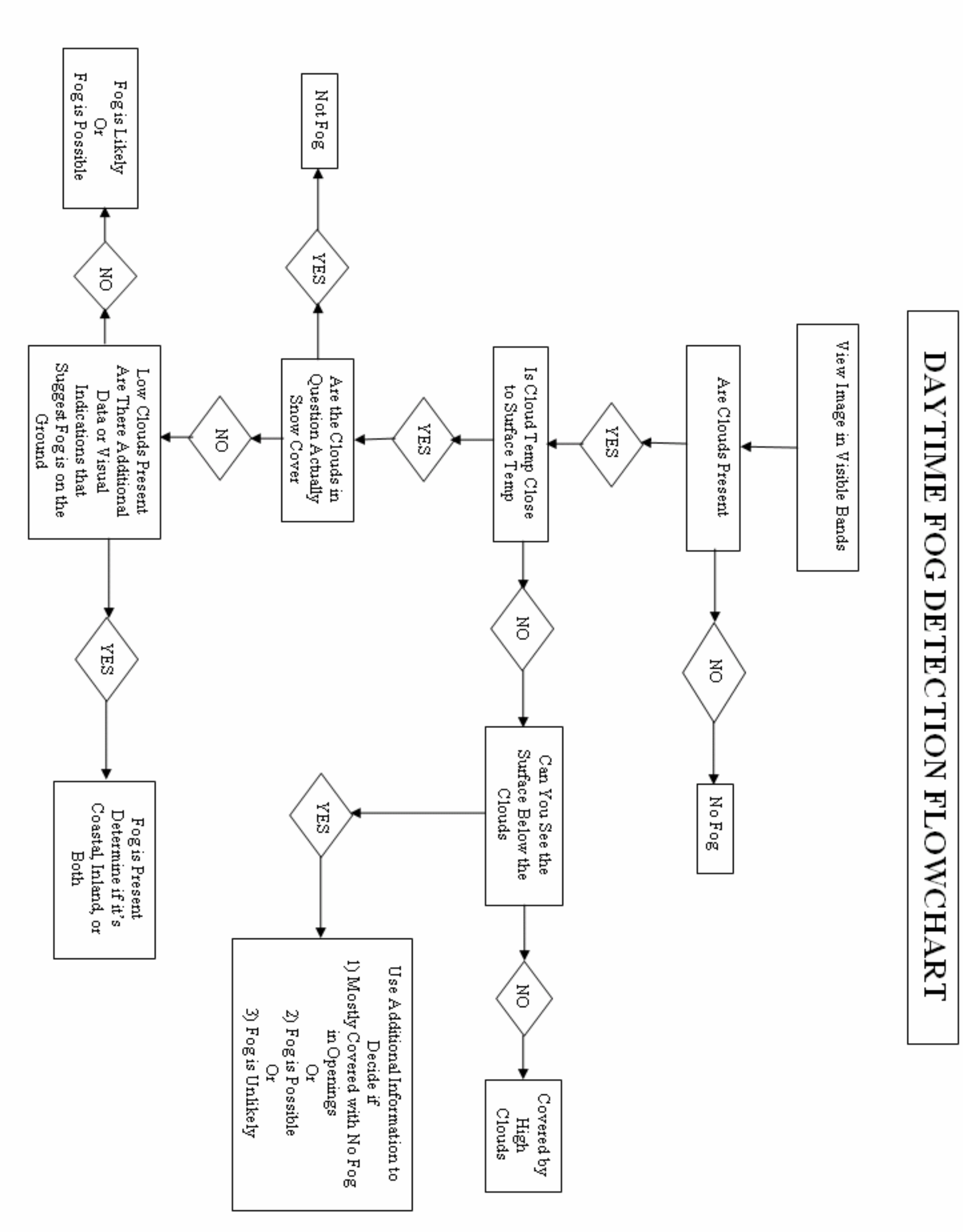

Figure 13. A decision tree describing the steps used to detect fog during the day with satellite imagery as the primary tool.

a. Nighttime Steps

The nighttime image analysis began with computing the 31 and 22 dual channel difference to enhance any low clouds in the scene. It also made sense to view the image with an IR band to determine high cloud coverage, but with so many images to see, going straight to the enhancement saved time. If no difference values were greater than one, fog was ruled out and it was determined if the area was cloud free or covered by higher clouds. Cloud free, meant no fog was present in that area, but if higher clouds were present, there were a few choices to make. When the cloud coverage was about 90 percent or greater, the area was considered to be completely covered by higher cloud. A category of, mostly covered with no fog seen in the cloud openings, was added to handle the situation when 50 percent or more of the area was blocked by high clouds. The more difficult decisions were made when less than 50 percent of the area was covered. There was enough evidence now with the help of surrounding areas, surface observations, and overall weather pattern, to decide if fog was possibly hidden under the clouds or was not likely present.

If clouds indicated difference values greater than one Kelvin on the fog enhanced image, further interrogation was needed for possible fog, but most fog events displayed difference values in excess of two Kelvin. When this occurred the next step was to use the brightness temperatures from the IR window channels 31 and 32 to determine the relative height of the cloud above the surface. A good rule was if the cloud and surface brightness temperatures differed by more than 10 degrees then, it was higher cloud; if less than five degrees apart, fog was likely; and if between the two, further investigation was needed. When it was determined that the clouds were elevated or that a false alarm occurred, the same procedures applied as above to determine a category based on extent of coverage and other contributing factors. Fog was less likely to be present when the temperature difference between surface and cloud was greater than five but it did happen. The complicated terrain across Korea made it possible. In this situation temperature profiles and surface observations were very helpful in declaring “fog”, or if other visual indications were obvious, they were used. For elevated low cloud (stratus or stratocumulus), the same decisions had to be made based on cloud coverage and

likeliness of fog hidden by the cloud, to determine a category. If no definite resolution could be reached between fog and elevated cloud, then it was decided that fog was simply a possibility. When the cloud and surface temperature difference was below five degrees, it was likely that fog was present and time to look for specific evidence that would confirm cloud was on the ground. Visual things to look for were: did the cloud follow the terrain, i.e., was it trapped in a valley or was it following a riverbed; was the texture smooth and opaque in appearance; and did the cloud mass have sharp distinct edges often seen with fog. Surface observations in the area were the best way to establish fog on the ground. Sometimes, reports of fog came from a distant location with similar characteristics, for example, up the coast but within the same body of sea fog. If any number of these indications were present then "fog" was determined to be in the area; on the other hand, if the cloud and surface temperature difference was the only evidence then fog was only considered to be likely.

b. Daytime Steps

The daytime procedures had the advantage of the visible bands, so the first step was to take advantage of them and view the image with the visible channels. Fog and other clouds with average thickness values were highly reflective in the visible wavelengths and easily detected by the satellites with these bands. This has been proven to be true in previous studies and was discussed in Chapter 1. If no clouds were detected then it was decided that no fog was present. When clouds were identified, the next step was to determine their relative height above the surface. The goal was to distinguish between low clouds and mid to high clouds by comparing the brightness temperature of the cloud to that of the surface whenever this was possible. At this point the process became very similar to the nighttime steps. If no low clouds were found then a category was chosen by the amount of higher cloud cover. It was decided if the surface was completely covered, mostly covered with no fog in the openings, or partially covered and fog was either possible or unlikely. If any low clouds were detected then they became the immediate focus of attention. The same surface and cloud temperature difference rule for night was applied to the daytime images. If the difference was greater than 10 Kelvin,

the clouds were considered elevated. If the difference was less than five Kelvin fog was likely, and if the difference was between five and 10 Kelvin further investigation was needed. The elevated clouds would then follow the same steps as the mid and upper-level clouds. The steps from the nighttime approach were used to determine if the remaining clouds were actually on the ground, with one following exception: During the winter months, it was possible to have snow cover in some areas. Snow, as discussed in Chapter I, reflects light in the visible bands just like fog and has brightness temperatures similar to the surrounding surface in IR bands, just like fog. So a snow enhancement had to be used during this study to eliminate any false fog readings due to snow cover. This was accomplished by combining the NIR channel 7 (where snow is very absorbing) with a shortwave infrared (SWIR) or visible channel (band 2 or 3) where snow is strongly reflective. The resultant image highlighted the snow with an assigned color, usually blue. From here the procedures for confirming fog became the same as in the nighttime steps.

With procedures in place, each image was examined. For each area of interest, a category was assigned. The data was collected and input into 16 separate spread sheets broken out by month, time of day, and satellite used. The complete set of raw data is shown in Appendix A. It is important to reiterate that if fog was detected anywhere in an area, it took precedence over all other categories for the entire area. Also, the area boundaries did not touch to provide complete coverage of the Korean peninsula (see Figure 12), so any fog found in between two areas was assigned to the closest one (or both if appropriate). This subjectivity was intentional since the satellite image spatial resolution could not resolve a thin boundary line between areas. This might cause statistical errors in the results but it was necessary for the decision making process.

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III. RESULTS

A. DATA SET AND CHARTS

As mentioned above, the complete set of spreadsheets containing the raw results was placed in Appendix A. Also, there were a number of different totals computed (see Appendix 2), to make useful comparisons of the results. The tabulations included all nine fog categories summed up for each individual month and then for the four months combined. Next, the categories were separated between nighttime and daytime results then, added for each month and the four months combined. Similarly, the data was divided into Aqua versus Terra results, then totaled by individual month, and finally combined for a four month total. The last breakdown using all nine categories was a complete separation of results by day and night and then by satellite before computing the totals.

The next approach involved isolating the dominant categories, “covered by higher cloud” and “fog”. Each breakout was handled in a different manner since the categories told distinctly different stories. When computing the totals the category “fog likely” was included with “fog.” The category “mostly covered by higher cloud” was combined with “covered by higher cloud” because of their similar impacts to operations. The “covered” and “mostly covered” isolation used every image to compute the monthly and four-month sums. This was to provide a higher temporal resolution in the statistical results. The fog totals on the other hand were computed in terms of days. One fog report out of the four images resulted in a fog day. The data was also broken down into daytime and nighttime fog totals, as well as Terra and Aqua fog totals. This only allowed two chances per day for each category to have fog. It’s important to note that “fog” and “fog likely” were not used for the same time period for one breakout. In other words, for the nighttime fog totals, if fog was identified in one or both of the images for one night then it was awarded a fog day. If no fog was identified but “fog likely” was reported then that night was awarded one “fog likely” day. It was similar to a binary, on/off or yes/no system with “fog” taking precedence over “fog likely” and only one awarded for each day. This was

done because the lack of continuous coverage made a temporal comparison less useful and fog days provided some good utility. The sums were again computed for each month and then all four months combined. The fog totals made it possible to compare this study with the previous climatology studies from Chapter 1. AFCCC (2007) and Kim and Lee (1970) used mean fog days computed for each month but Guttman (1978) had the months broken down further into four observation times (00, 06, 12, and 18 UTC). In order to make a more accurate comparison with Guttman (1978), the fog totals were broken down by individual satellite pass. This gave four separate results per day for each month with approximate times at 0130, 0430, 1330, and 1630 UTC. To make the analysis process easier or at least more pleasant the spreadsheets were transformed into bar charts (see Figures 14-89). The bar charts were grouped by category with a description of each group in the following paragraphs. Noticeable patterns or trends in the results were discussed in the Results Summary Section.

The first set of bar charts indicates, for each area of interest, the number of satellite images where the surface was covered or mostly covered by higher clouds. Figure 14 shows the total number of images for the entire four month period and Figures 15-18 separated the totals by month. The results give an approximation for how often satellite detection of fog would not be available due to the presence of higher clouds in the area.

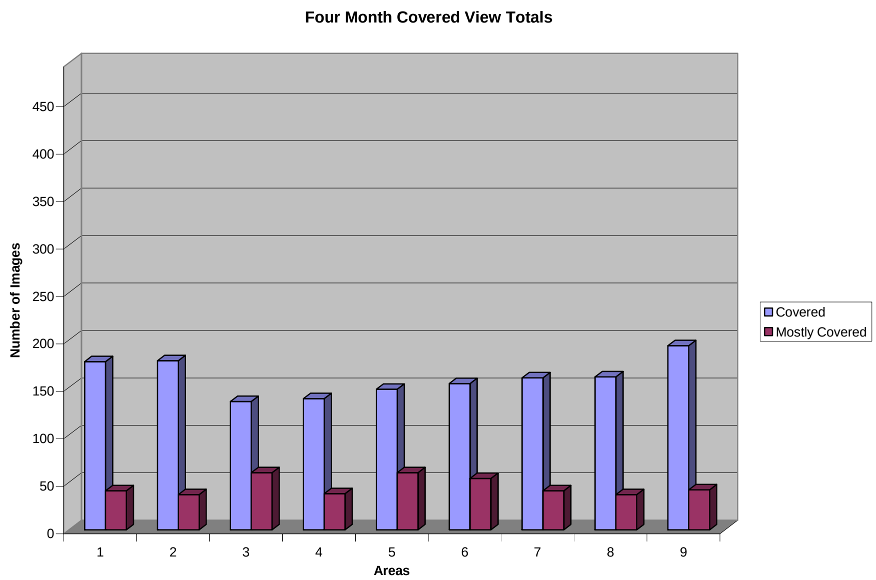

Figure 14. The total number of images from the four month study period that had full coverage (covered) or nearly full coverage (mostly covered) of high clouds. Results from all nine areas of interest are shown.

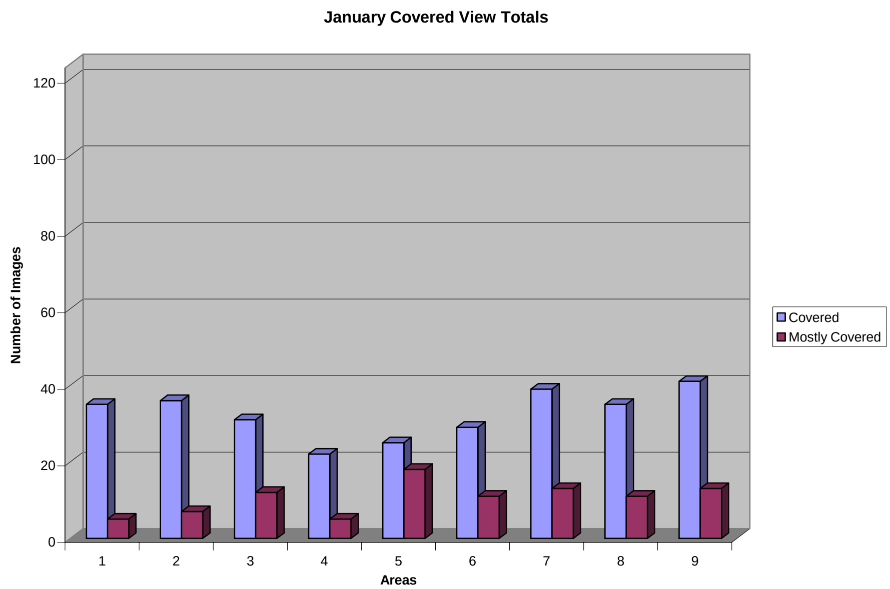

Figure 15. Same as in Figure 14, except for the month of January only.

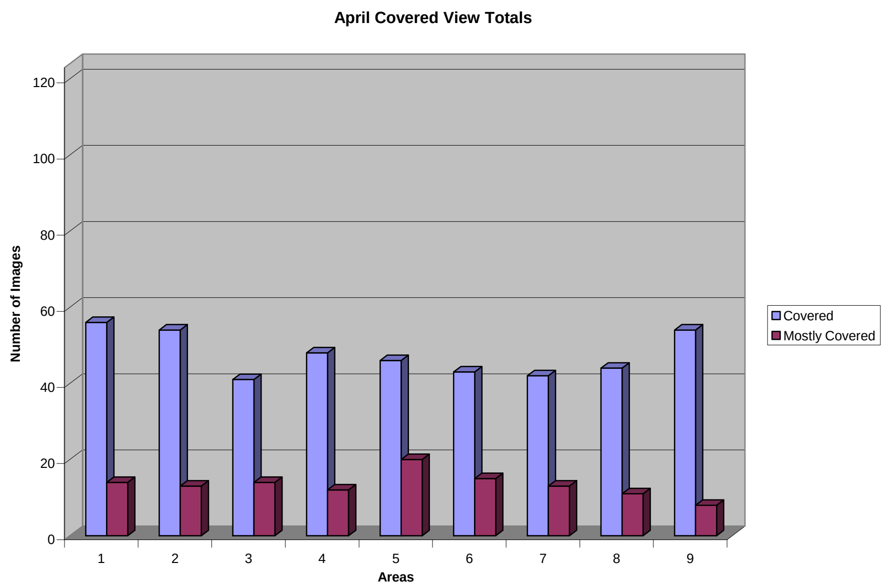

Figure 16. Same as in Figure 14 except for April only.

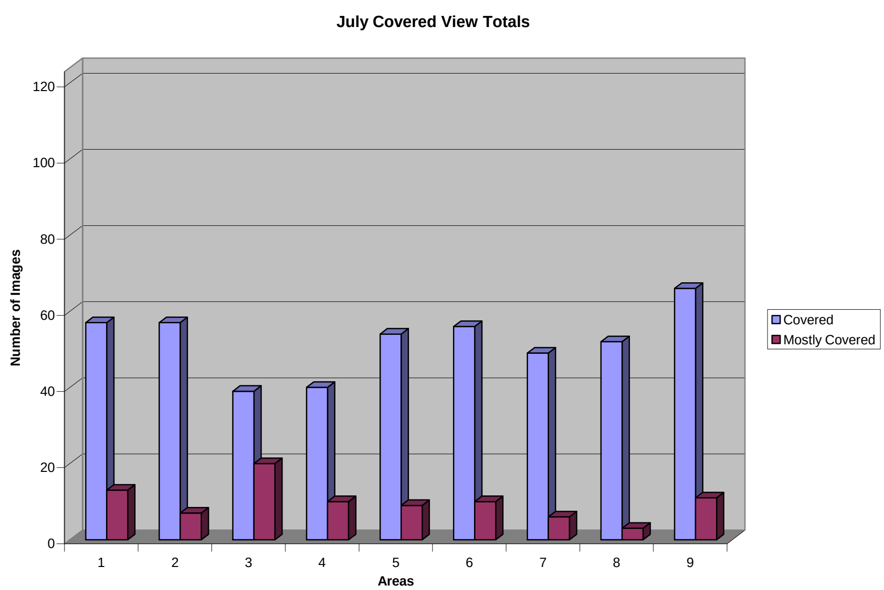

Figure 17. Same as in Figure 14, except for July only.

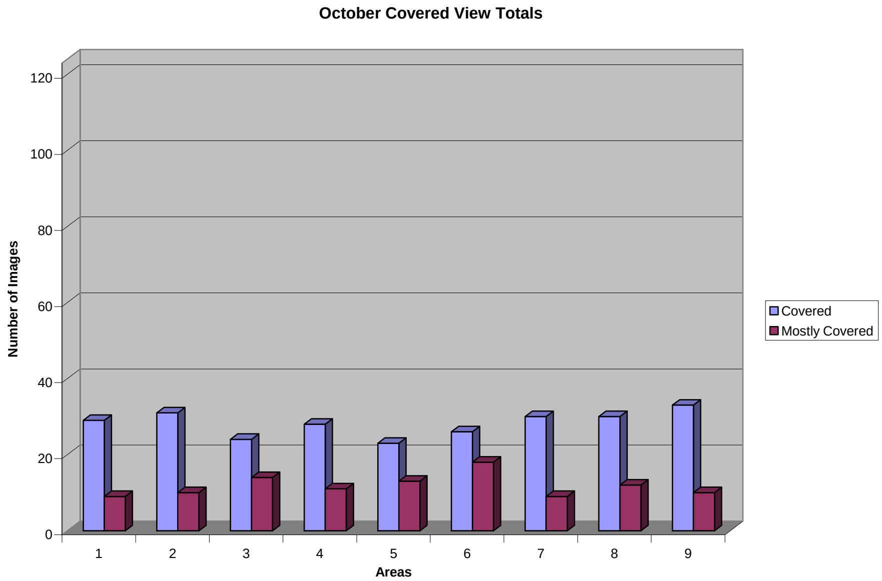

Figure 18. Same as in Figure 14, except for October only.

The next few results are all related to fog day totals but with slight variations. Fog likely results were always included in the fog day charts. Figure 19 sums the number of fog days and fog likely days for the entire four month period and Figure 20-23 provide the totals for each month. These totals imply expected values for fog during each month and for the four month period.

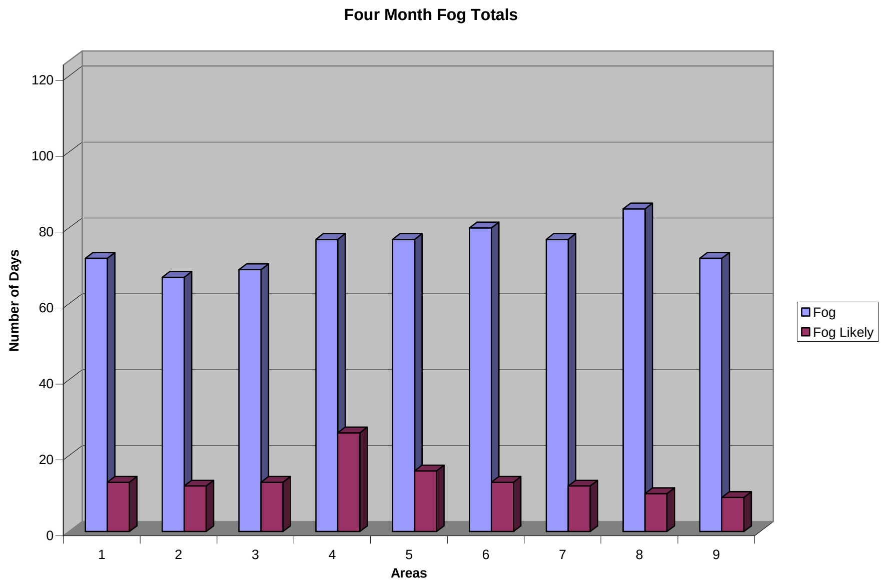

Figure 19. The total number of days from the four month study period with reports of fog or fog likely. Results from all nine areas of interests are shown.

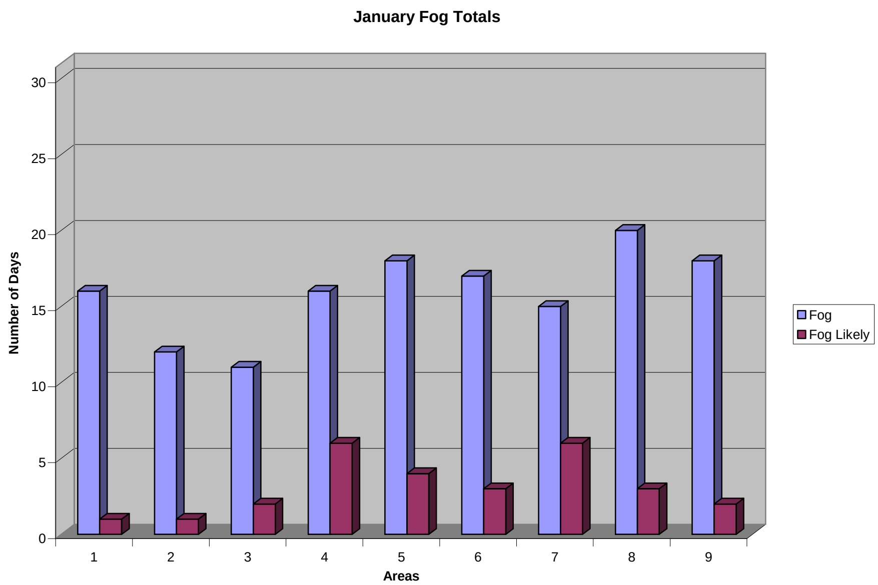

Figure 20. The total number of days in January with reports of fog or fog likely, for each area of interest.

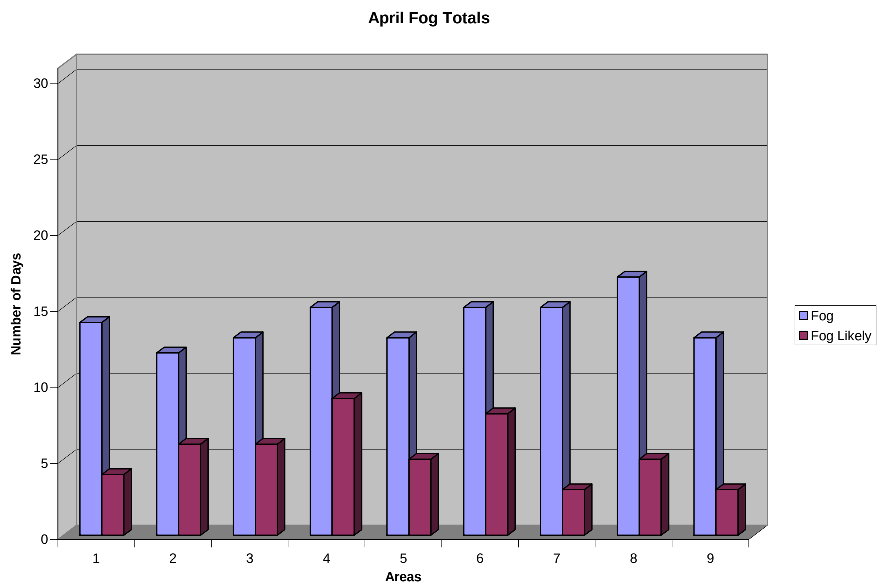

Figure 21. The total number of days in April with reports of fog or fog likely, for each area of interest.

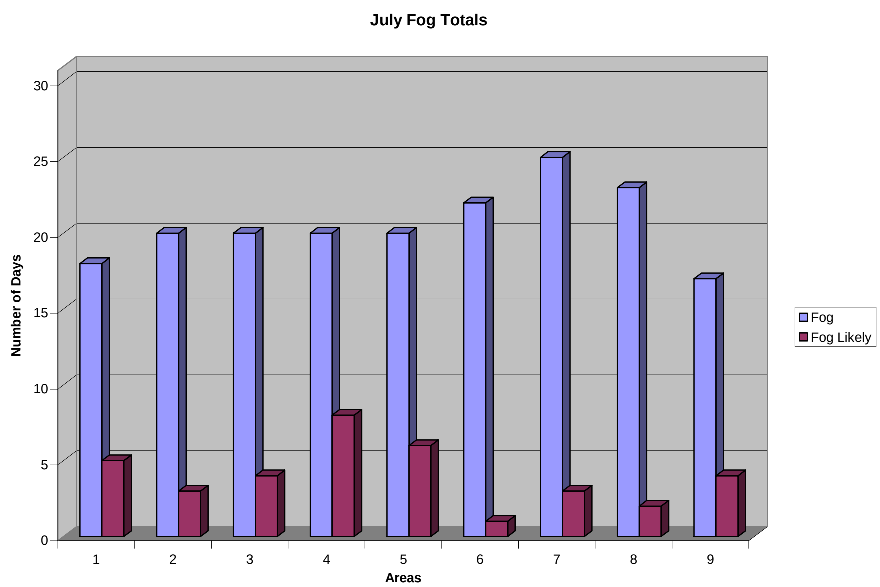

Figure 22. The total number of days in July with reports of fog or fog likely, for each area of interest.

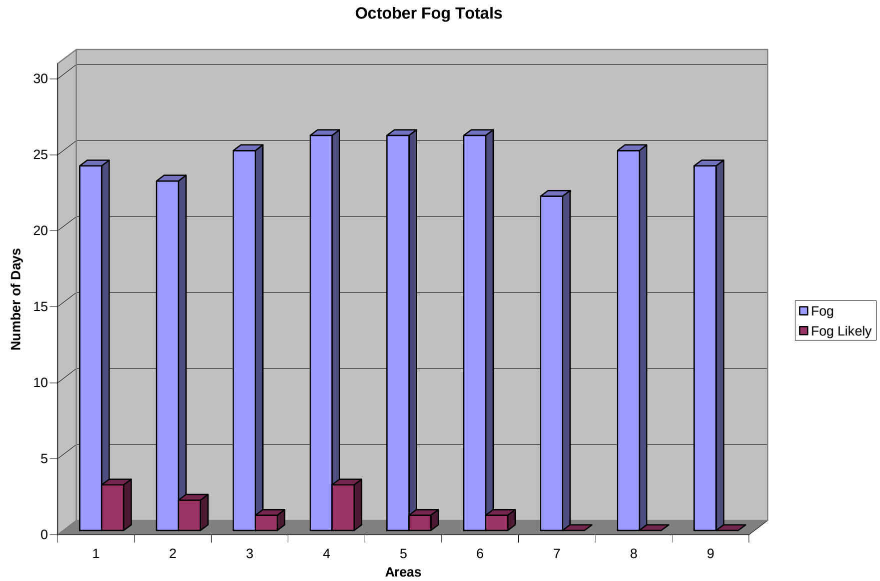

Figure 23. The total number of days in October with reports of fog or fog likely, for each area of interest.

The fog days were also divided into daytime and nighttime results. Figure 24 displayed the total of daytime and nighttime fog days for the four months combined while Figures 25-28 have the information broken down by month. This obviously compared the number of days with fog seen at night with the number of days identified in the daytime images.

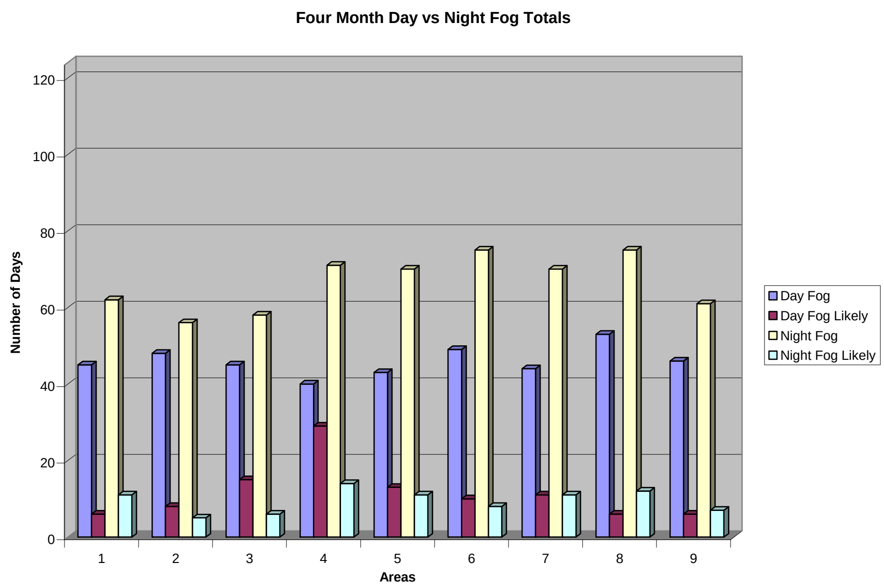

Figure 24. Comparison of the four month total of daytime and nighttime fog or fog likely scenes, for each area of interest.

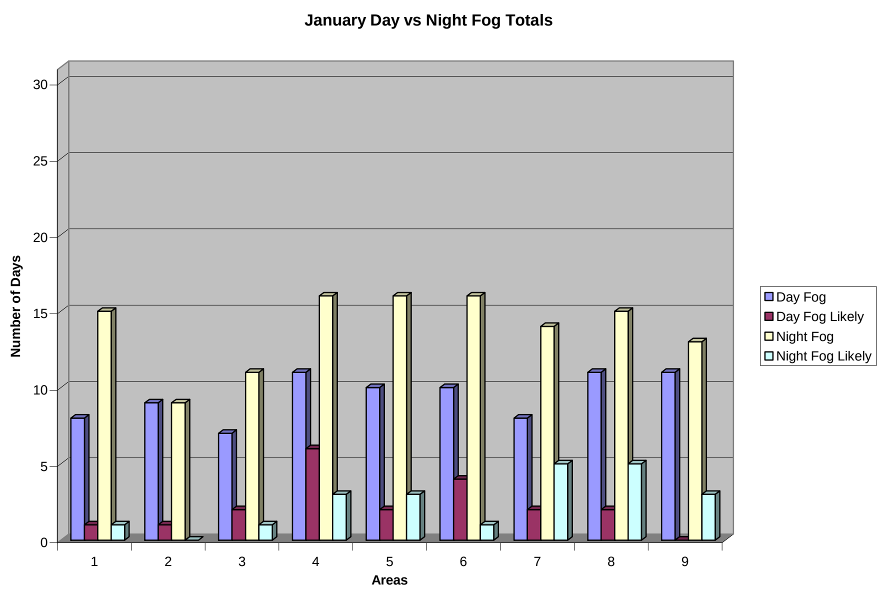

Figure 25. Same as in Figure 24, except for the month of January.

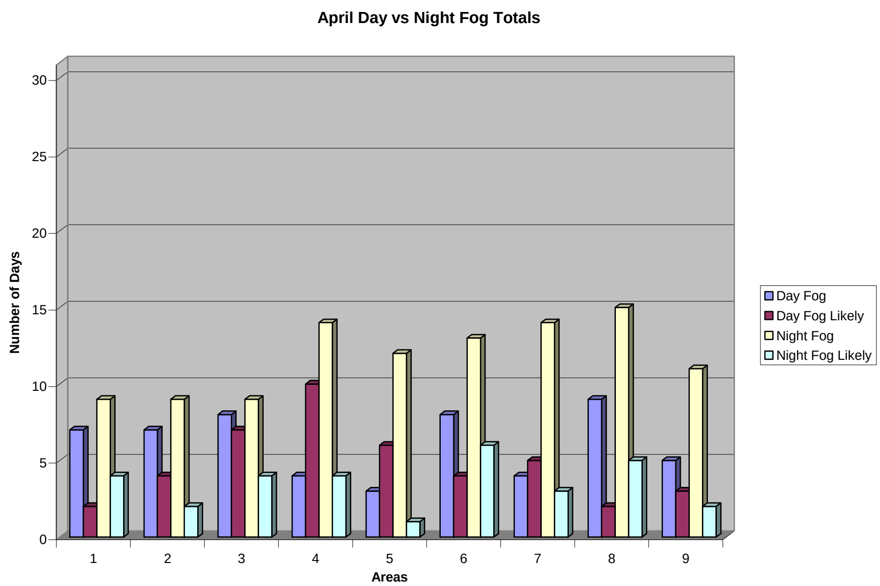

Figure 26. Same as in Figure 24, except for the month of April.

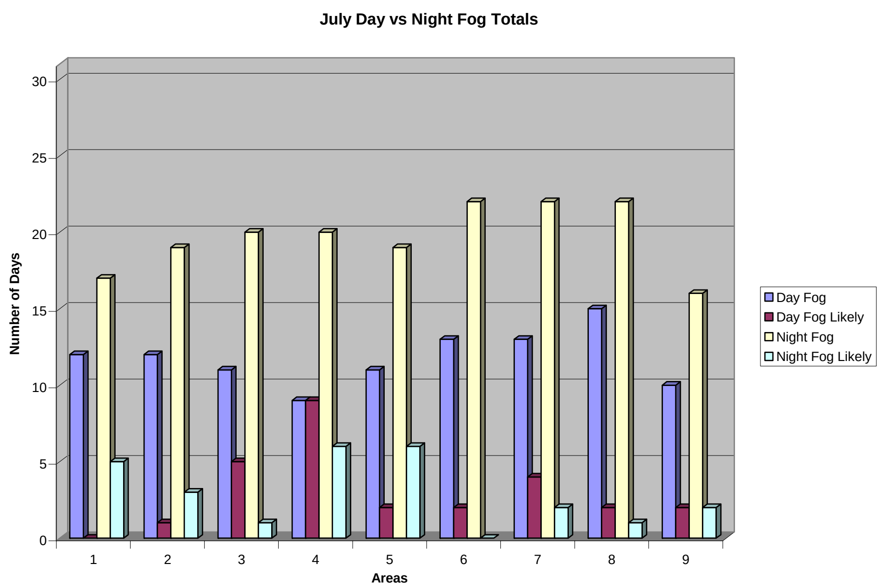

Figure 27. Same as in Figure 24, except for the month of July.

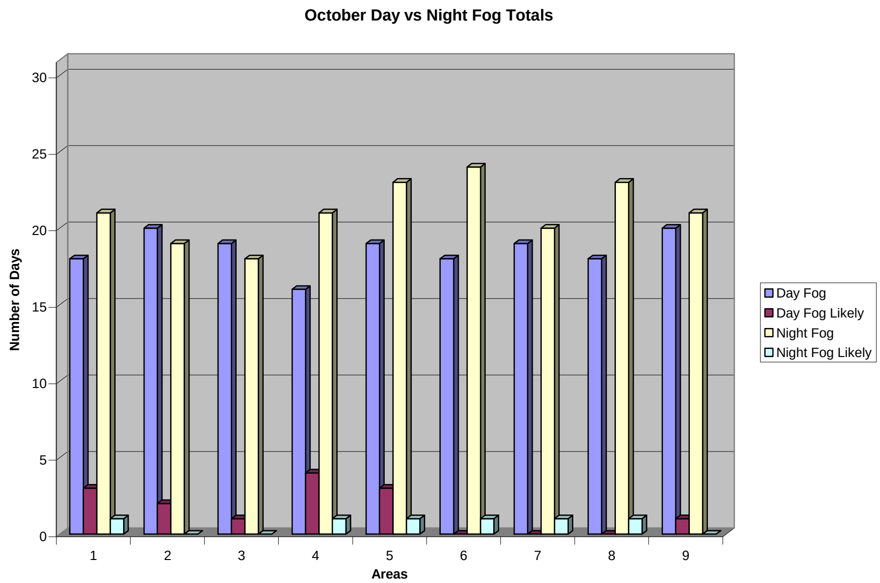

Figure 28. Same as in Figure. 24, except for the month of October.

The next group of fog day bar charts compared the amount seen from the Aqua satellite with the total from the Terra satellite. So the four images from each day were broken into two categories, Aqua and Terra. Just like the day night breakout if either image (one daytime and one nighttime) for each satellite had fog in a specific area then that area was given one fog day for the appropriate satellite. If neither image had fog but did have a fog likely report, that area was awarded a fog likely day for the appropriate satellite. Figure 29 showed the entire four month totals for both satellites and Figures 30-33 displayed the same information for each month. Since the satellites were scanning Korea three hours apart, it was important to look for any trends in fog detection based on the satellite differences.

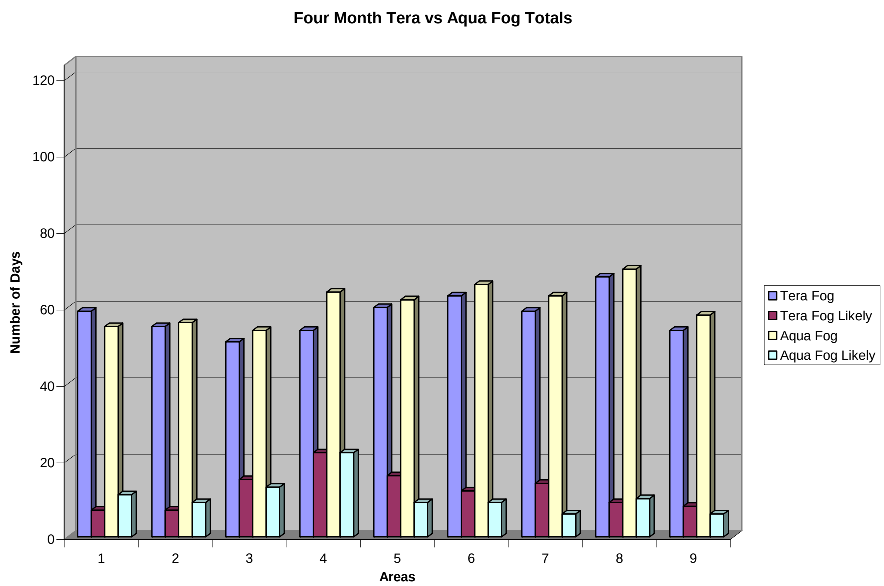

Figure 29. Comparisons of the four month total number of fog and fog likely days detected from the two MODIS satellites, Aqua and Tera, respectively. Results from all nine areas of interests are shown.

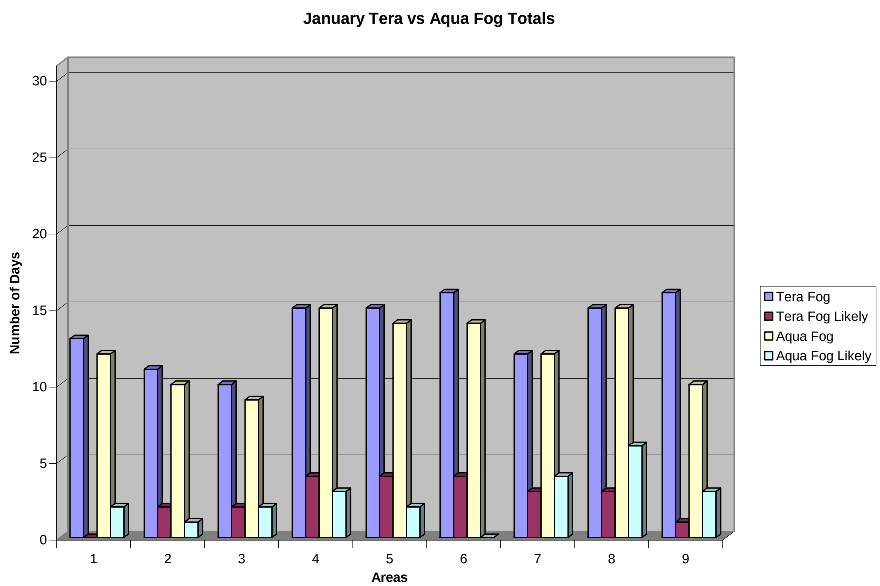

Figure 30. Same as in Figure 29, except for the month of January only.

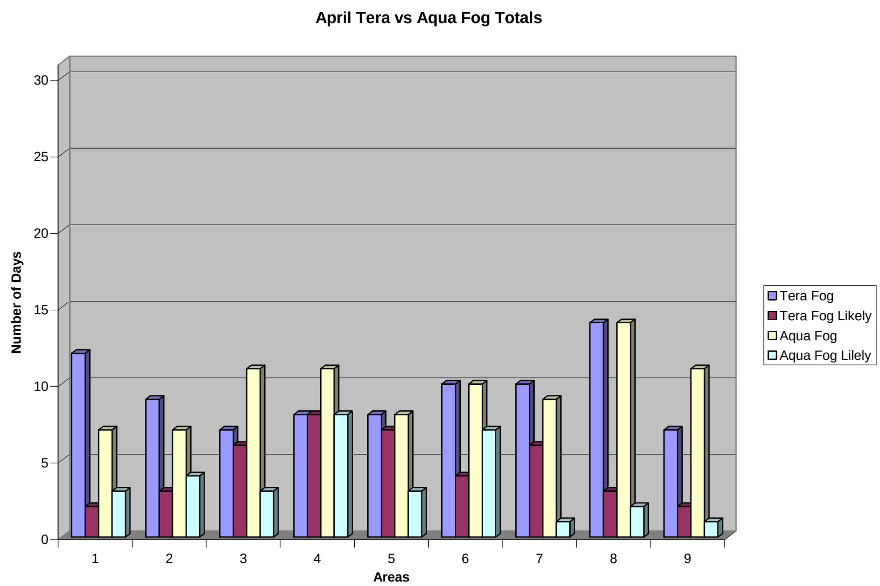

Figure 31. Same as in Figure 29, except for the month of April only.

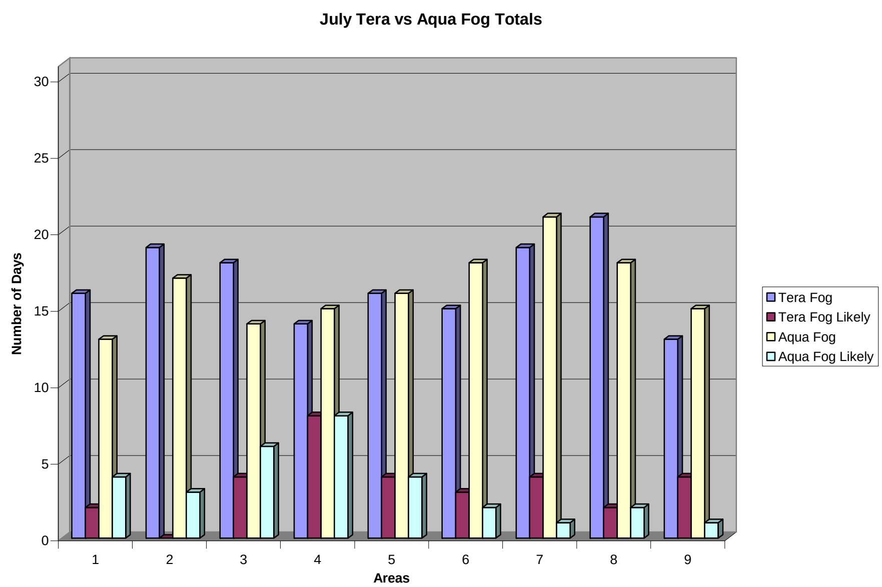

Figure 32. Same as in Figure 29, except for the month of July only.

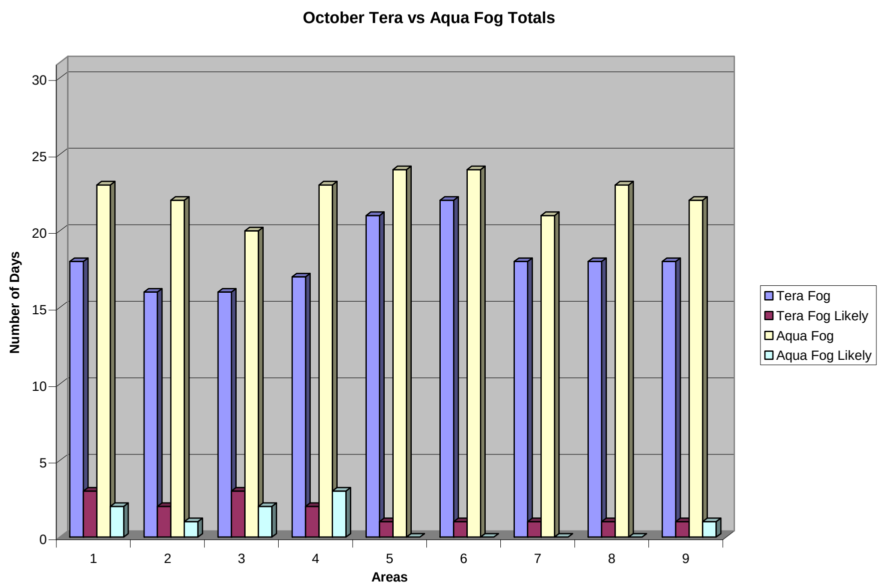

Figure 33. Same as in Figure 29, except for the month of October only.

The final group of fog day totals was computed for each satellite pass for a given month. The results were broken down by daytime, nighttime, satellite, and month. This gave an estimate for the expected fog days seen at approximately 0130, 0430, 1330, and 1630 UTC (pass times of each satellite) for each month in a given area. This allowed a deeper fog day investigation between each satellite and also created a nice format for a comparison with the Guttman (1978). Figure 34-37 displayed the fog days and Figures 38-41 showed the fog likely days, for every satellite pass each month.

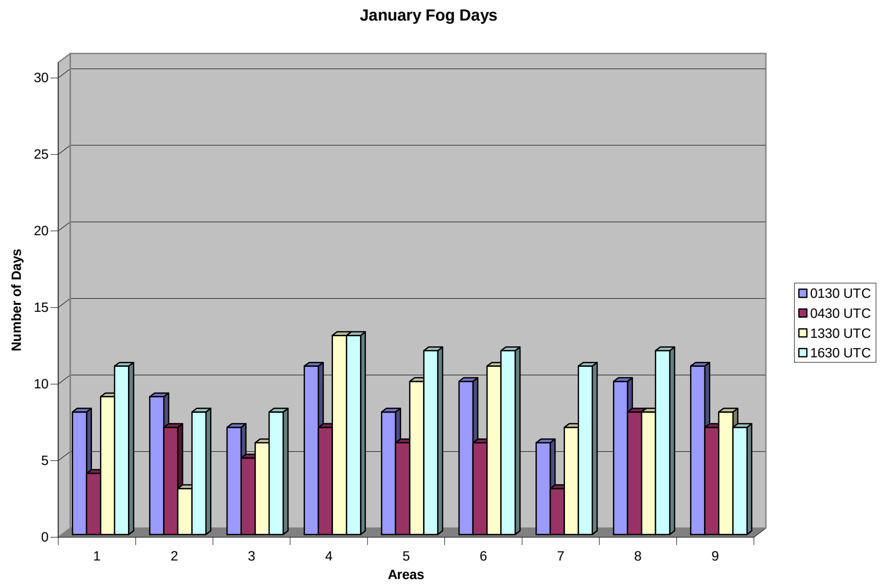

Figure 34. The total number of days in January with reports of fog, for each area of interest, separated by the individual satellite passes.

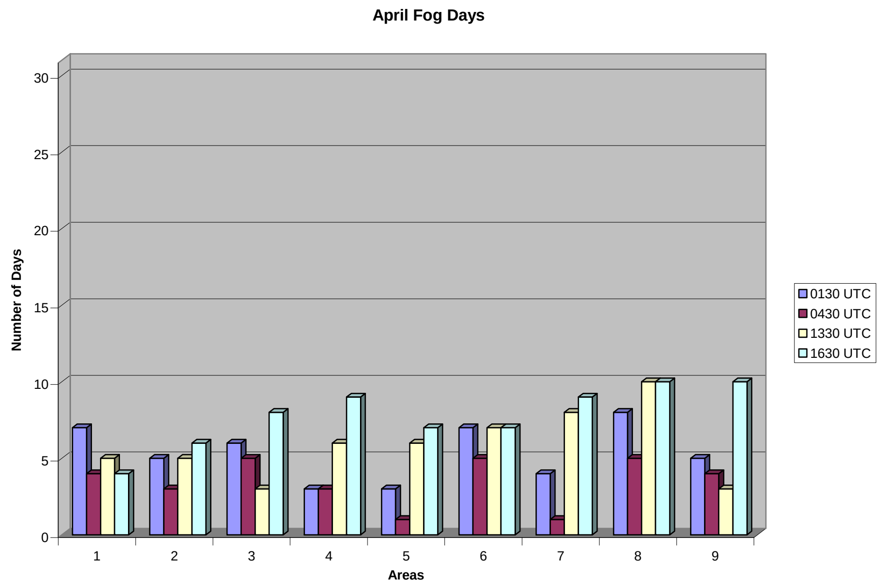

Figure 35. The total number of days in April with reports of fog, for each area of interest, separated by the individual satellite passes.

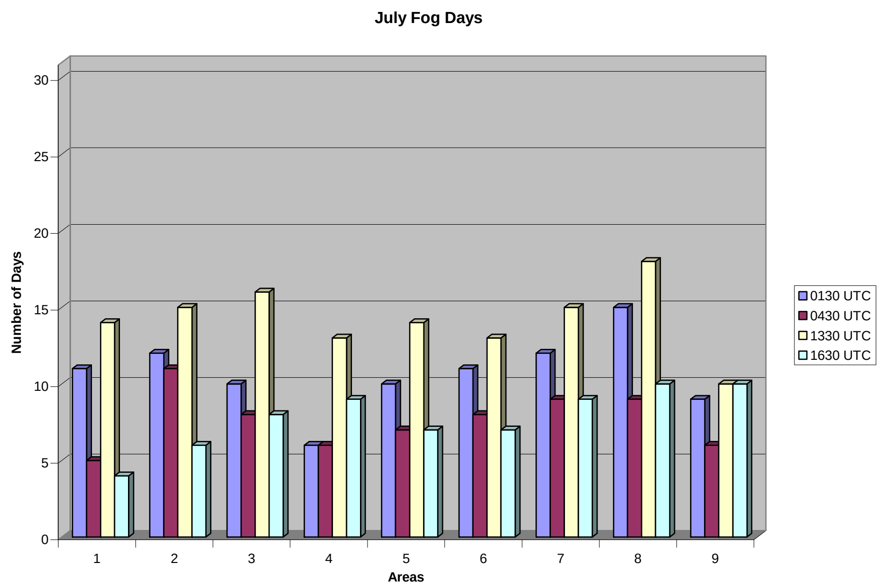

Figure 36. The total number of days in July with reports of fog, for each area of interest, separated by the individual satellite passes.

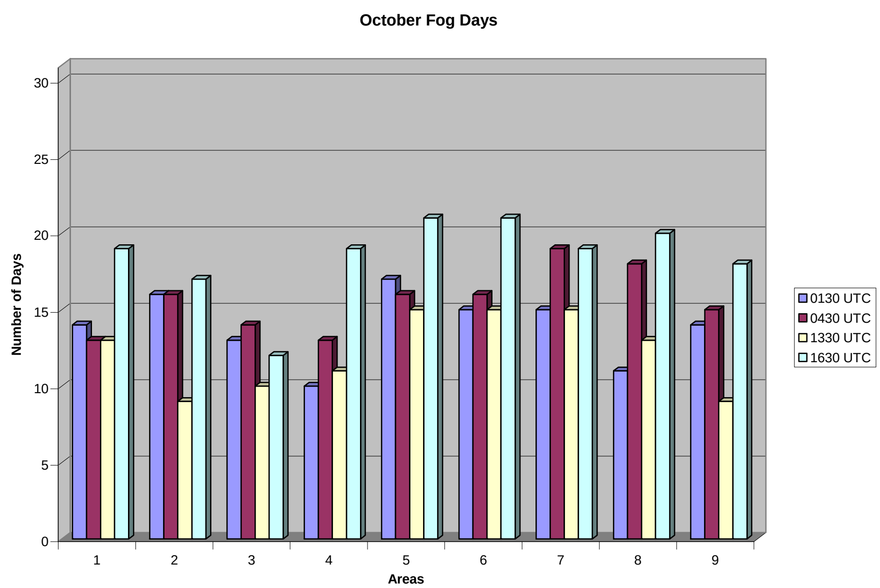

Figure 37. The total number of days in October with reports of fog, for each area of interest, separated by the individual satellite passes.

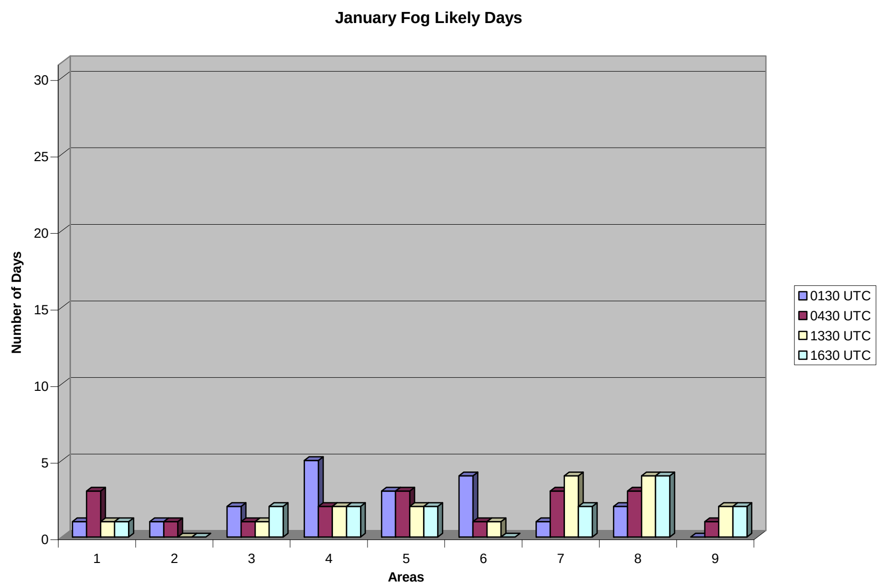

Figure 38. The total number of days in January with reports of fog likely, for each area of interest, separated by the individual satellite passes.

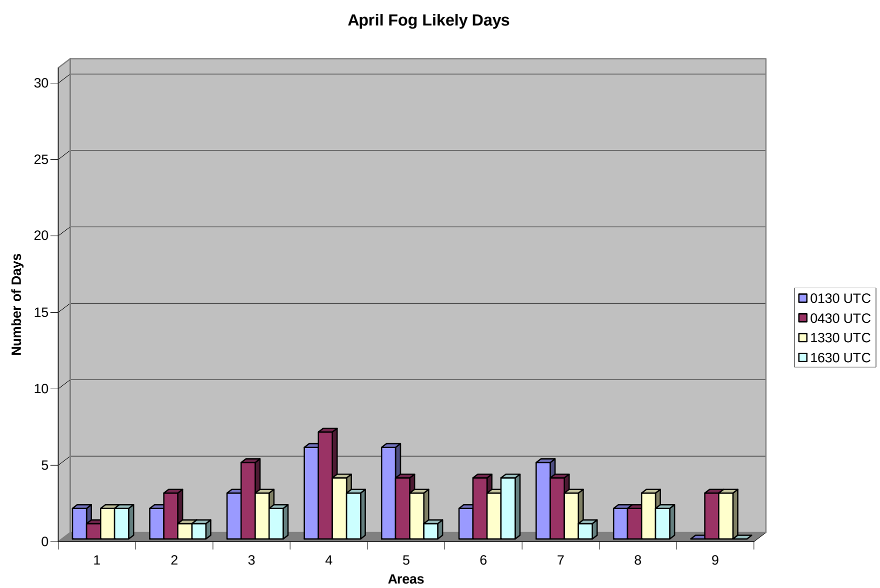

Figure 39. The total number of days in April with reports of fog likely, for each area of interest, separated by the individual satellite passes.

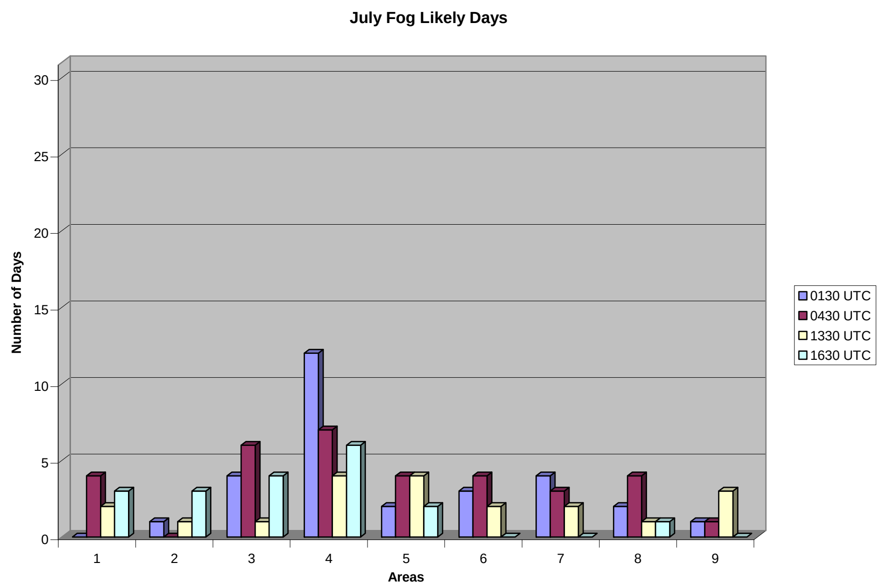

Figure 40. The total number of days in July with reports of fog likely, for each area of interest, separated by the individual satellite passes.

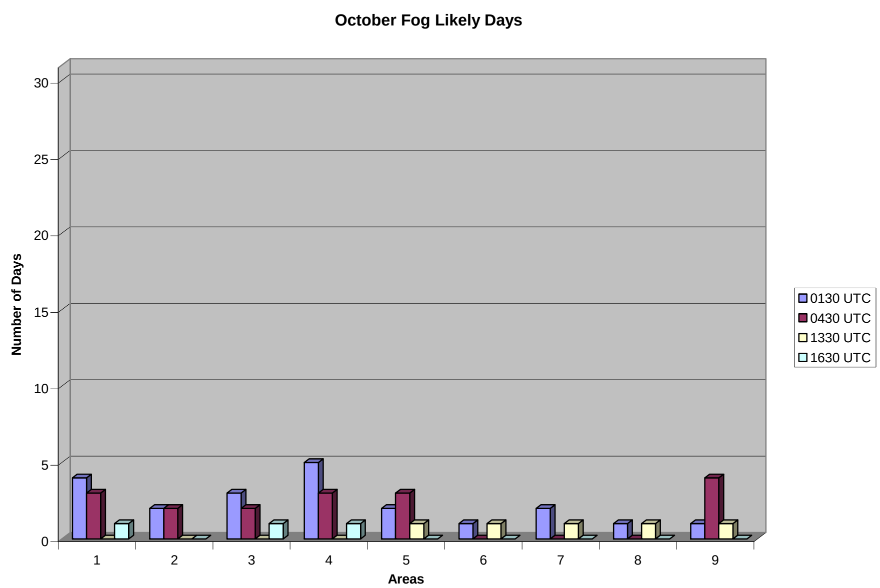

Figure 41. The total number of days in October with reports of fog likely, for each area of interest, separated by the individual satellite passes.

The remaining groups of charts displayed totals for all nine fog categories. The first group looked at the results as a whole. Figure 42 showed the four month total for all categories in each area of interest. Figures 43-46 separated the same information out for each month. This allowed a simple comparison between each category and identified the dominant events.

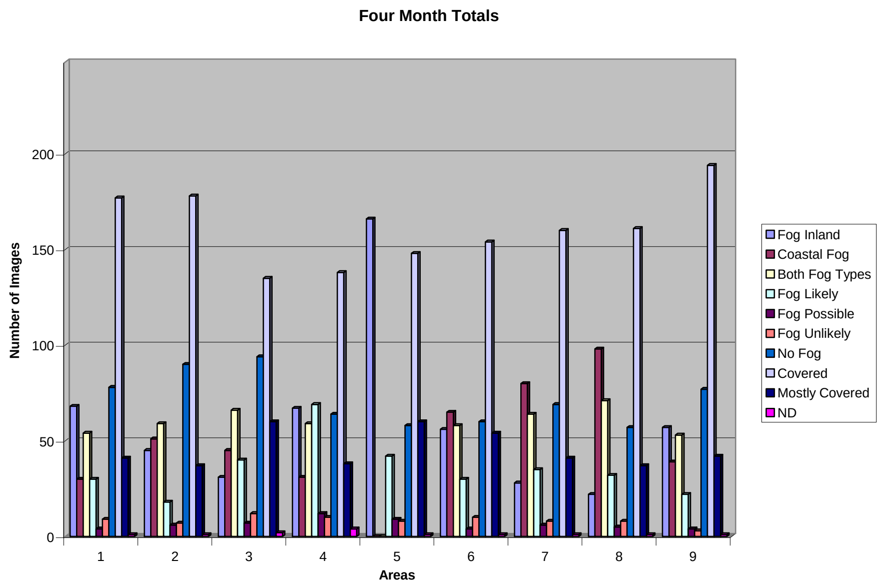

Figure 42. The four month total number of reports for each category, in all nine areas of interest.

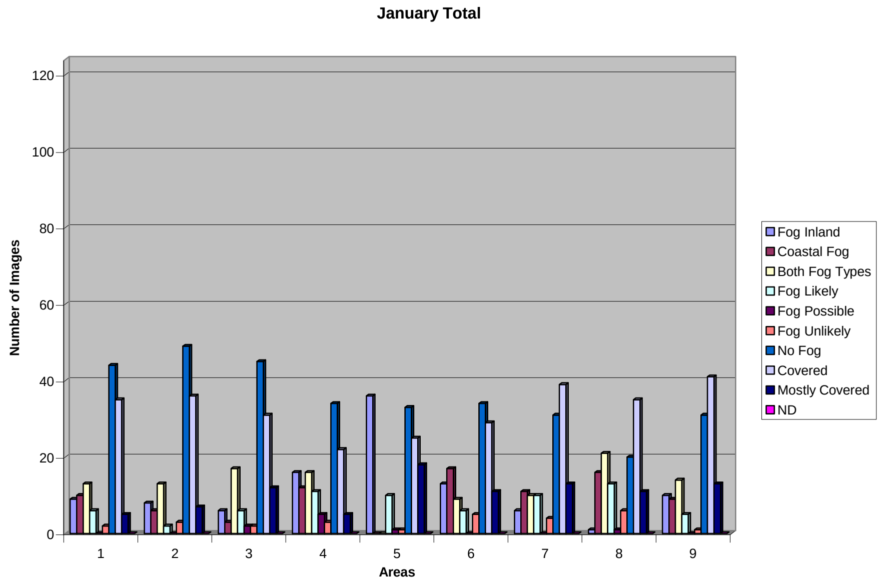

Figure 43. The total number of reports for each category in January, for all nine areas of interest.

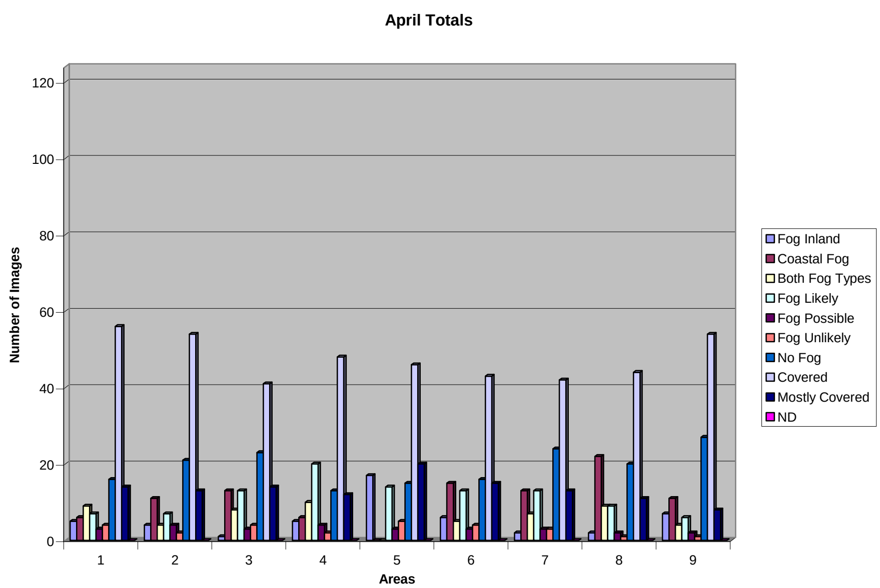

Figure 44. The total number of reports for each category in April, for all nine areas of interest.

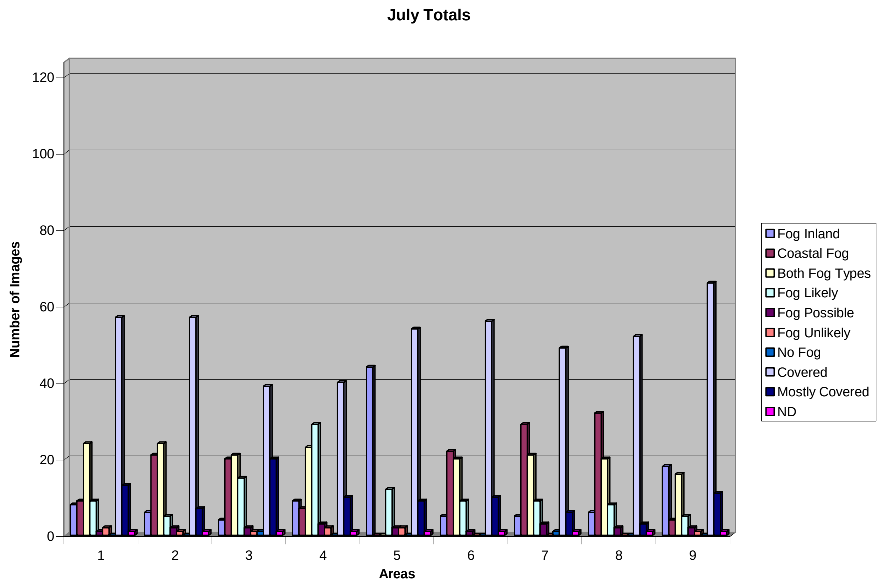

Figure 45. The total number of reports for each category in July, for all nine areas of interest.

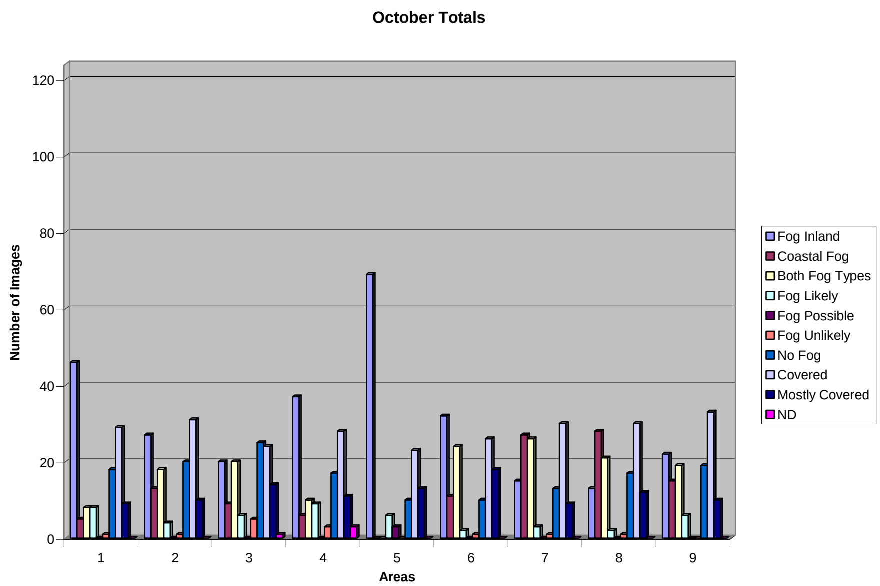

Figure 46. The total number of reports for each category in October, for all nine areas of interest.

Next, the data was divided into daytime and nighttime totals. Figures 47 and 48 displayed the four month daytime and nighttime totals respectively and Figures 49-56

provided the nighttime and the daytime totals for each month for all categories. This information of course indicated patterns or differences in the results based on day versus nighttime images.

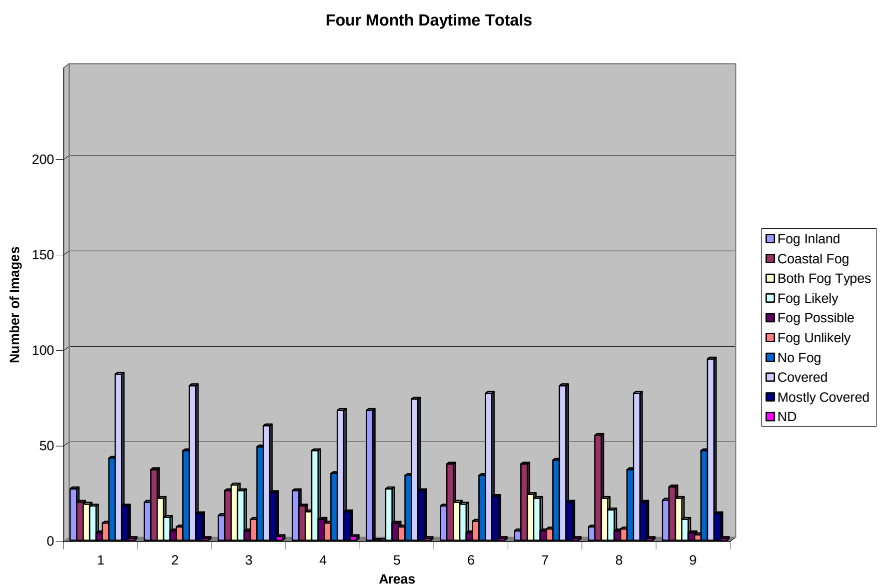

Figure 47. The four month total number of reports for each category in a daytime image, for all nine areas of interest.

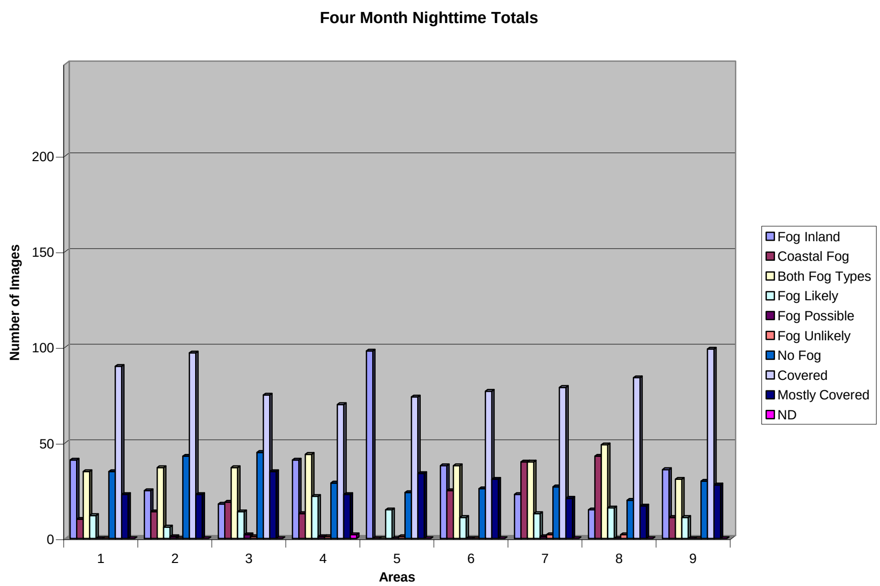

Figure 48. The total number of reports for each category in a nighttime image, for all nine areas of interest.

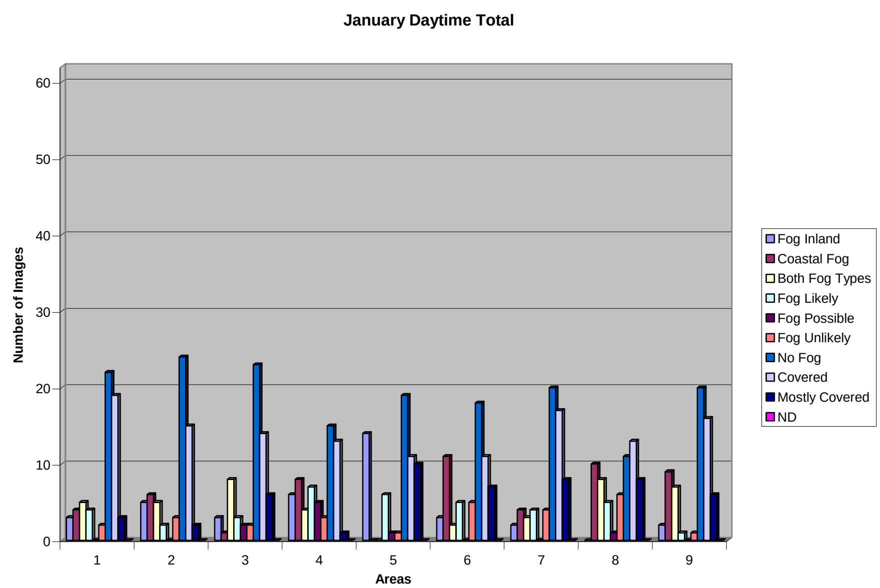

Figure 49. The total number of reports for each category in a daytime January image, for all nine areas of interest.

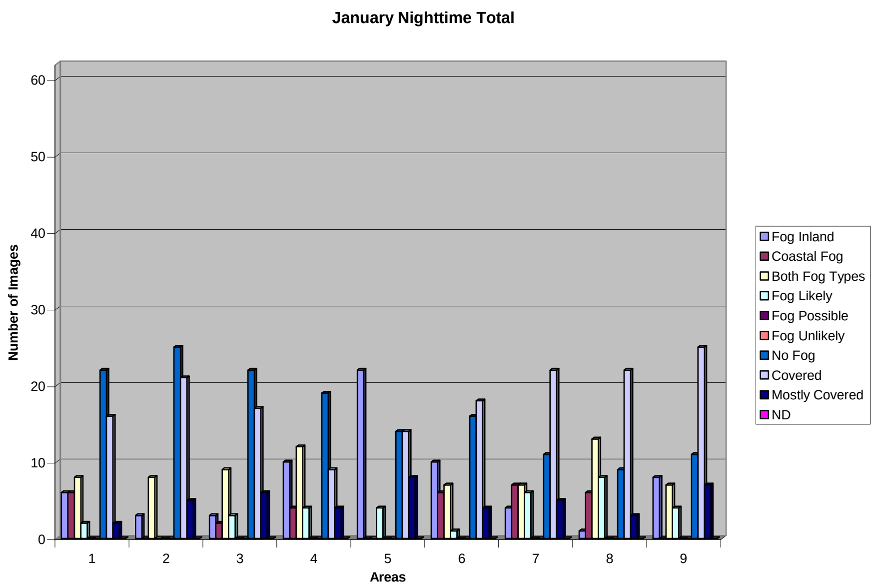

Figure 50. The total number of reports for each category in a nighttime January image, for all nine areas of interest.

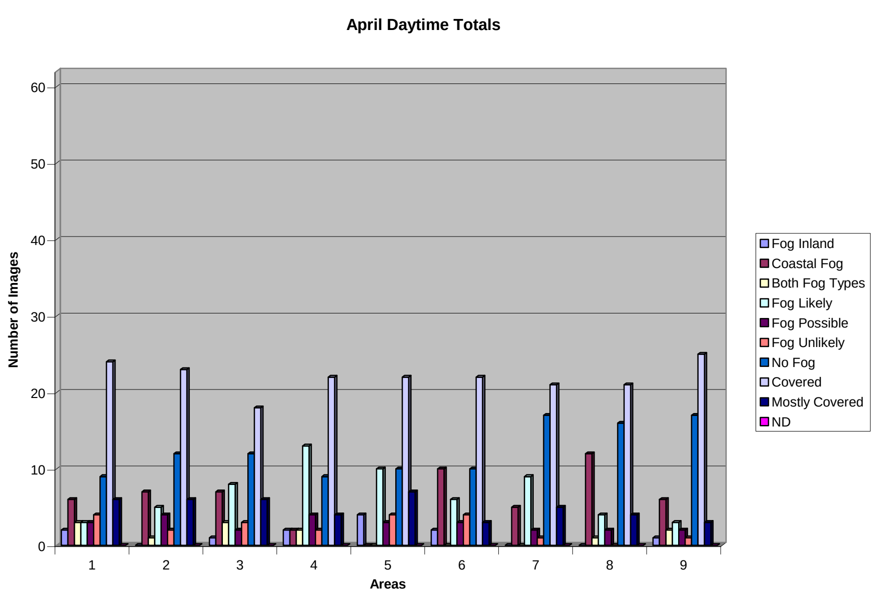

Figure 51. The total number of reports for each category in a daytime April image, for all nine areas of interest.

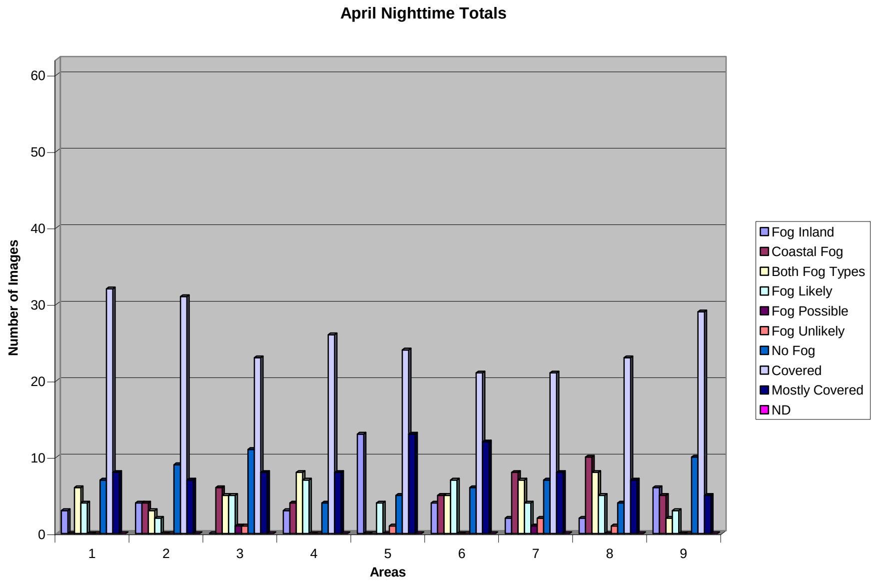

Figure 52. The total number of reports for each category in a nighttime April image, for all nine areas of interest.

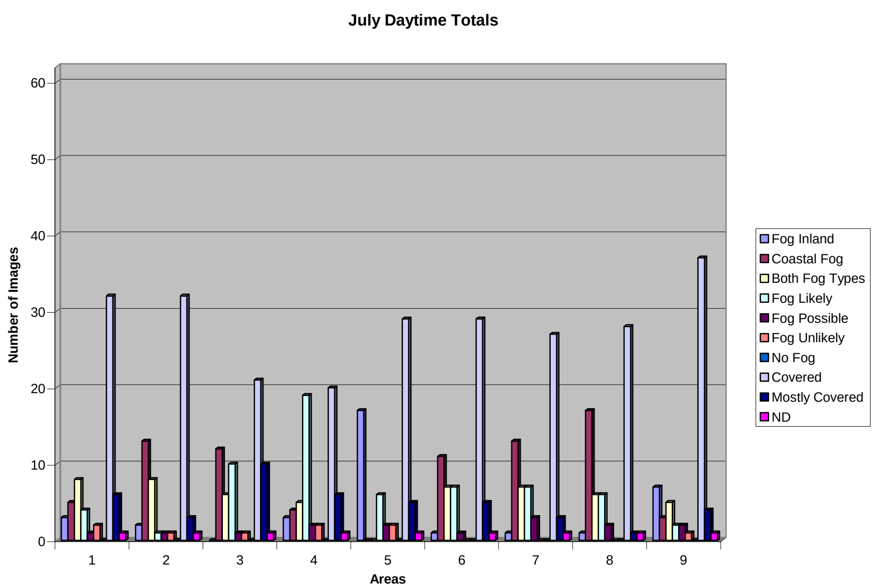

Figure 53. The total number of reports for each category in a daytime July image, for all nine areas of interest.

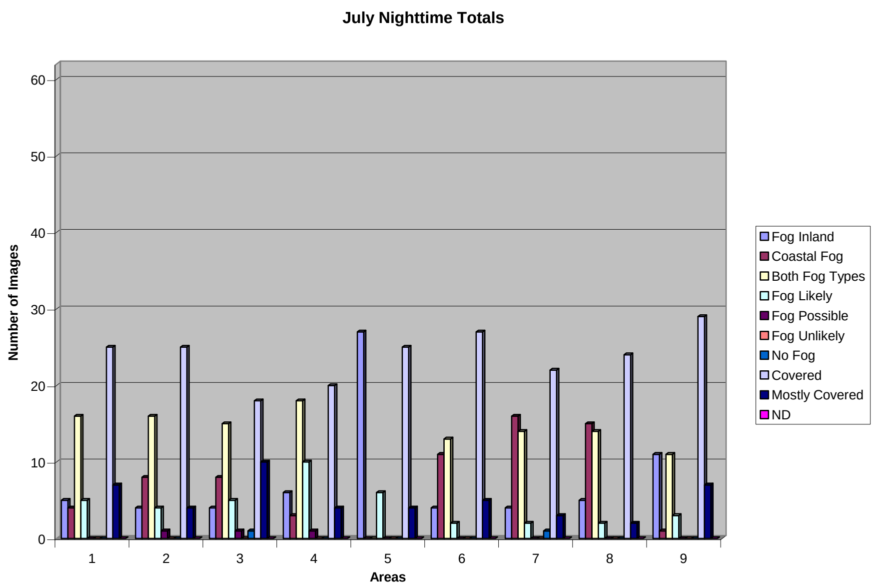

Figure 54. The total number of reports for each category in a nighttime July image, for all nine areas of interest.

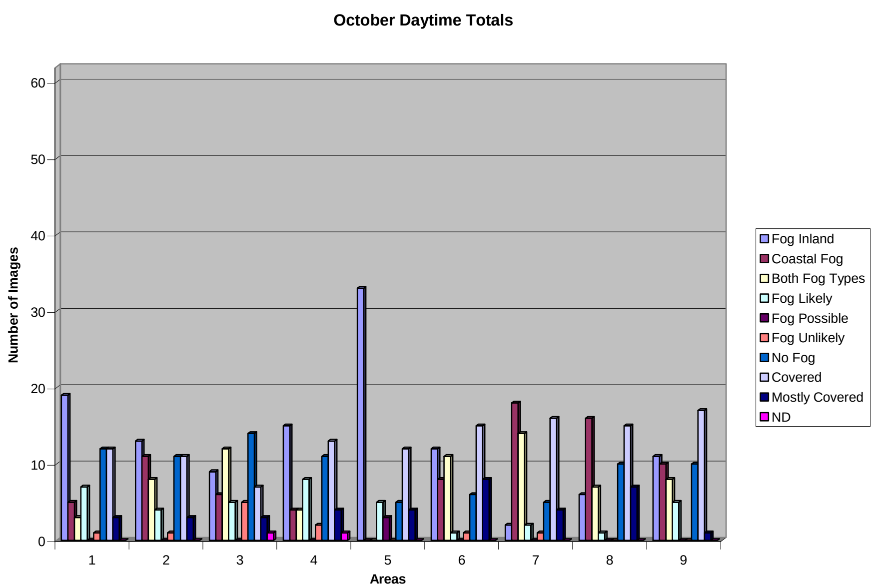

Figure 55. The total number of reports for each category in a daytime October image, for all nine areas of interest.

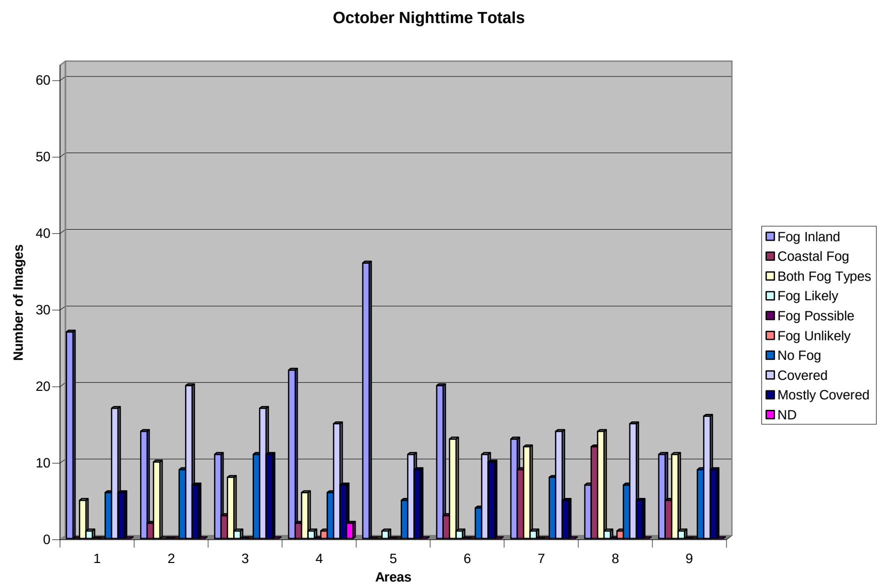

Figure 56. The total number of reports for each category in a nighttime October image, for all nine areas of interest.

The data was also broken down by satellite; totals were computed separately for the Terra and Aqua images. Figures 57 and 58 showed the four month Aqua and Terra totals for each category. Figures 59-66 provided Aqua and Terra totals for each month. Again this information gave insight into trends in the results based on the different satellites.

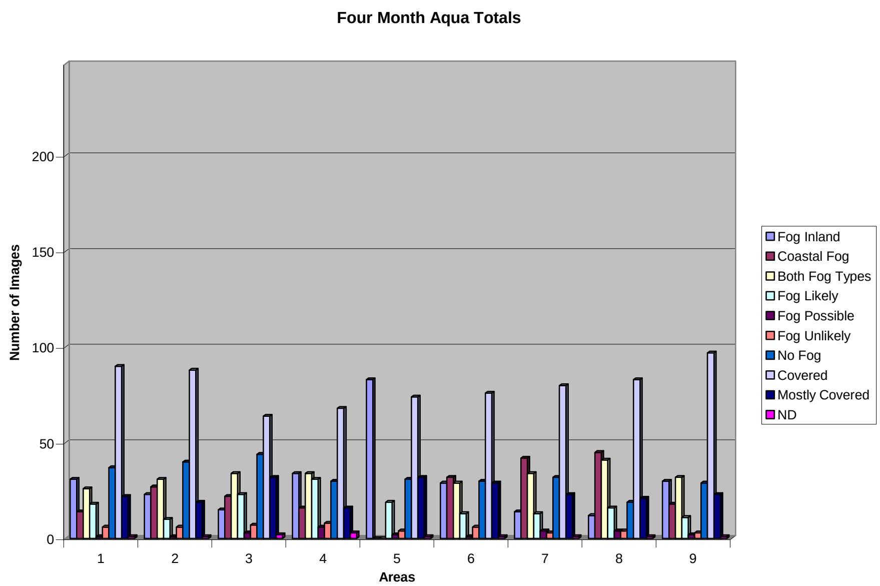

Figure 57. The four month total number of reports for each category in an Aqua image, for all nine areas of interest.

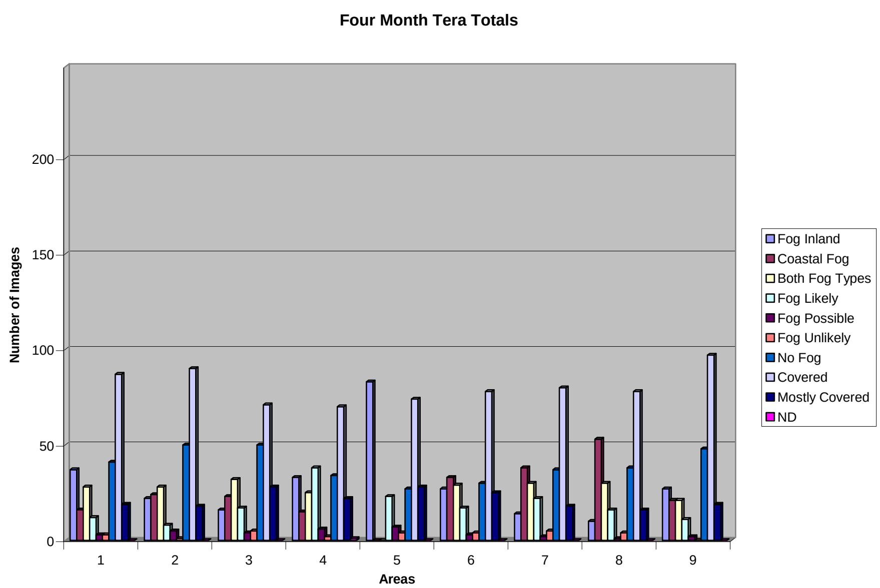

Figure 58. The four month total number of reports for each category in a Terra image, for all nine areas of interest.

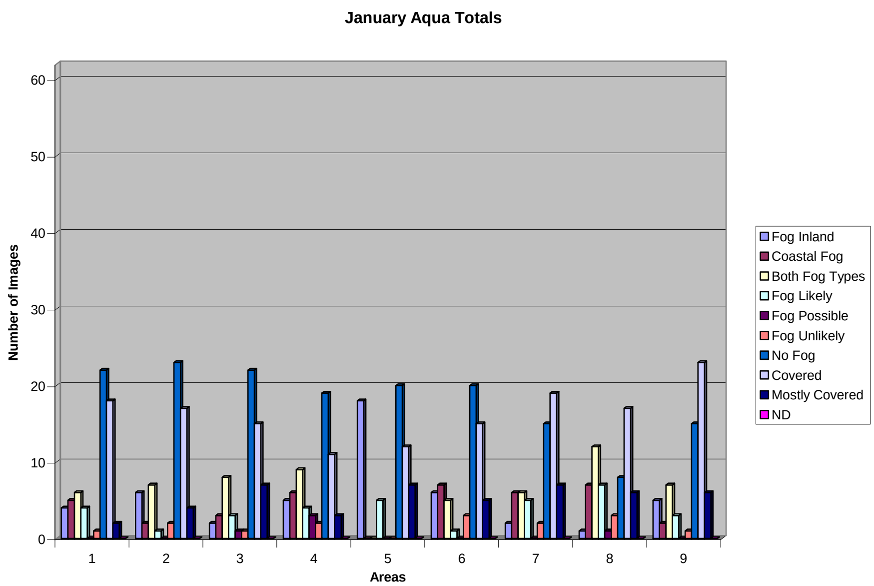

Figure 59. The total number of reports for each category in a January Aqua image, for all nine areas of interest.

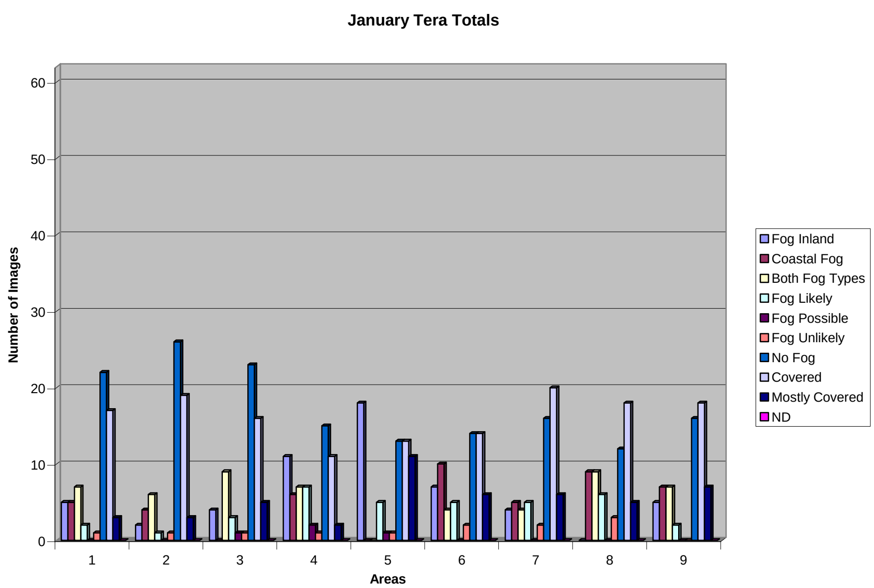

Figure 60. The total number of reports for each category in a January Terra image, for all nine areas of interest.

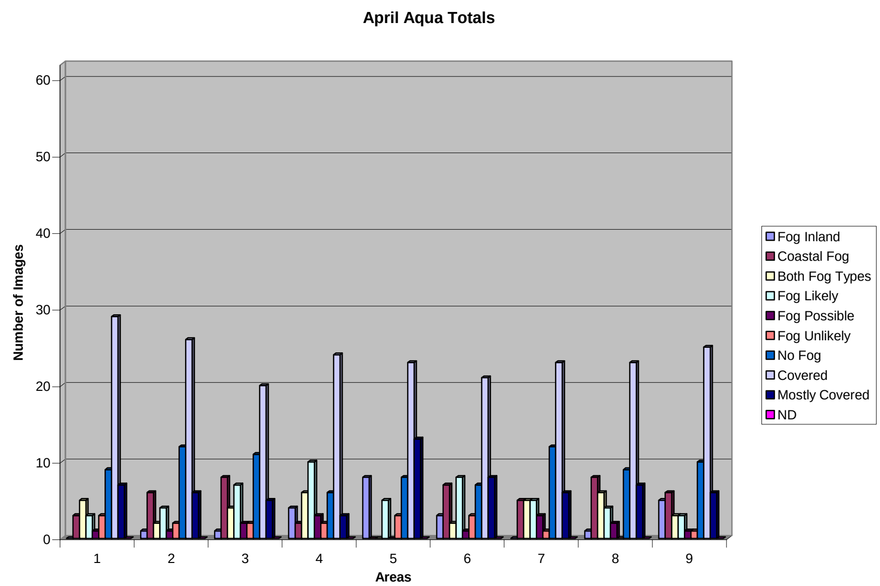

Figure 61. The total number of reports for each category in an April Aqua image, for all nine areas of interest.

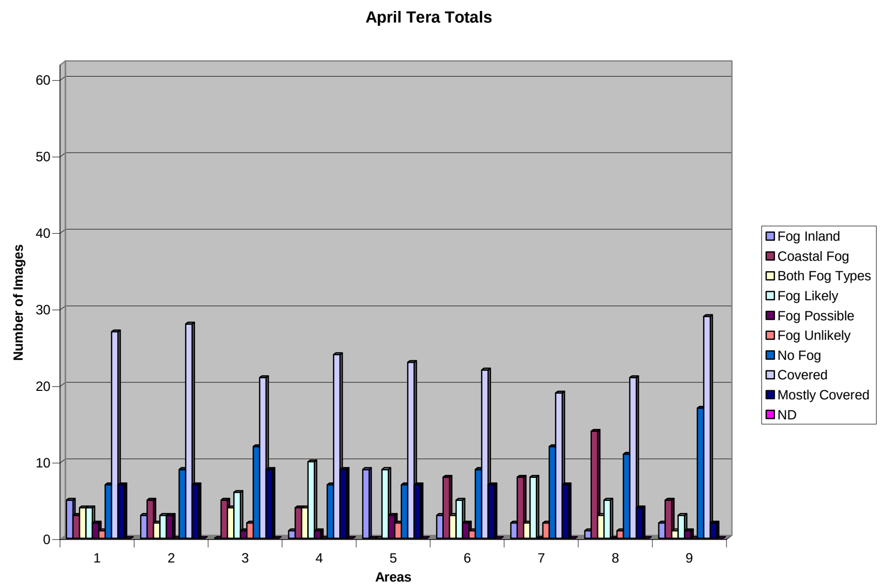

Figure 62. The total number of reports for each category in an April Terra image, for all nine areas of interest.

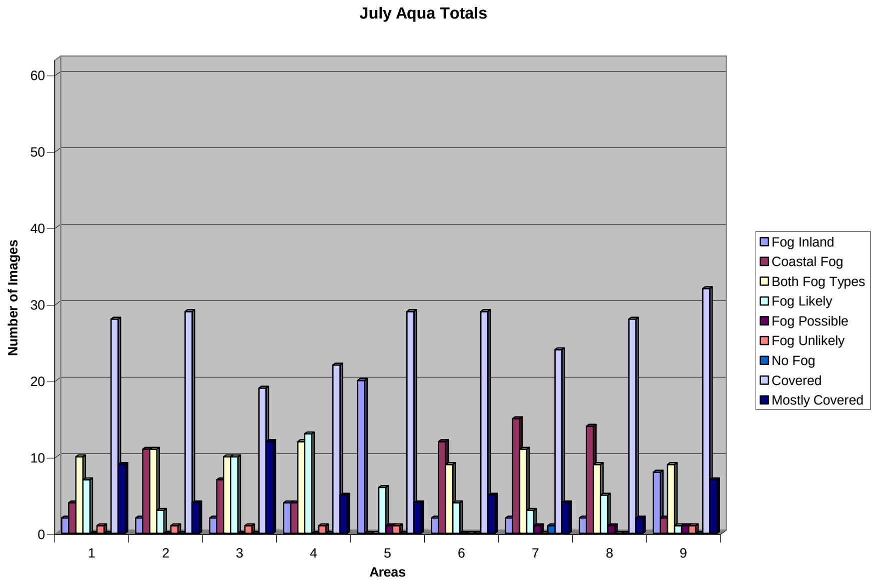

Figure 63. The total number of reports for each category in a July Aqua image, for all nine areas of interest.

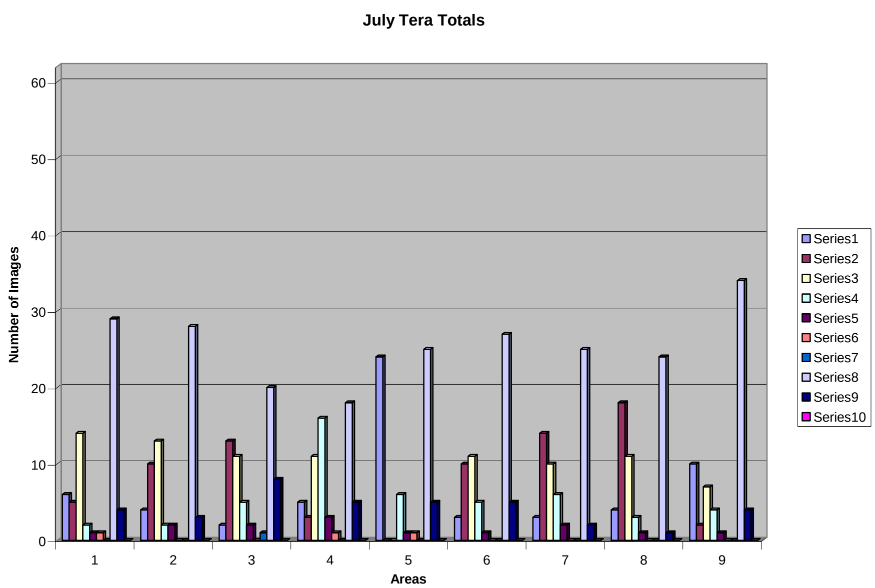

Figure 64. The total number of reports for each category in a July Terra image, for all nine areas of interest.

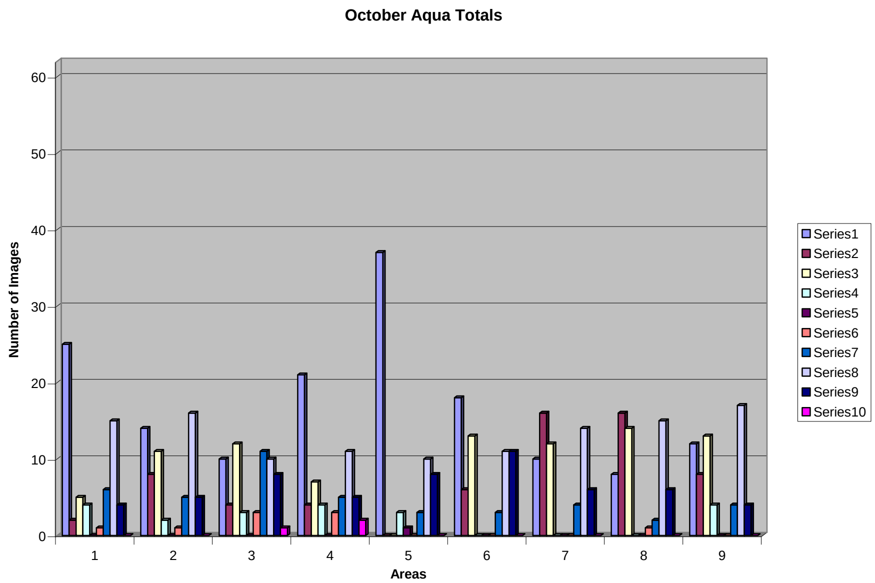

Figure 65. The total number of reports for each category in a October Aqua image, for all nine areas of interest.

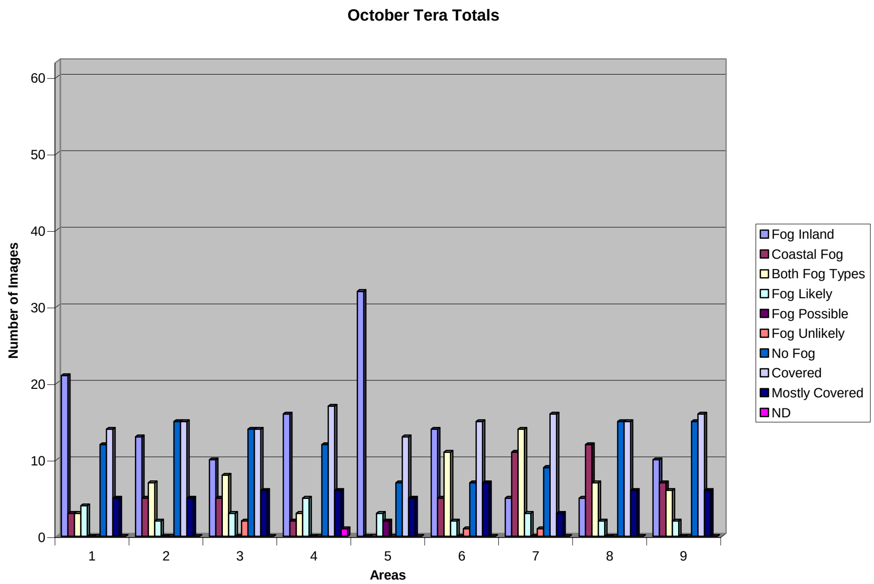

Figure 66. The total number of reports for each category in a October Terra image, for all nine areas of interest.

Finally each fog category was totaled for each satellite pass. The data was broken down by day, night, satellite, and month. Figures 67-82 displayed the results and provided a tool for the most detailed comparisons available for this data.

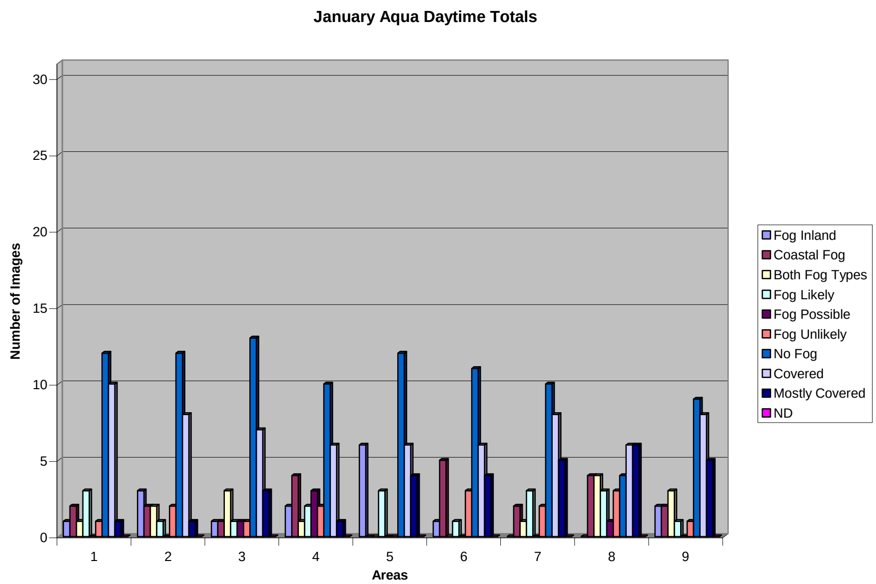

Figure 67. The total number of reports for each category in January for the Aqua daytime images, in all nine areas of interest.

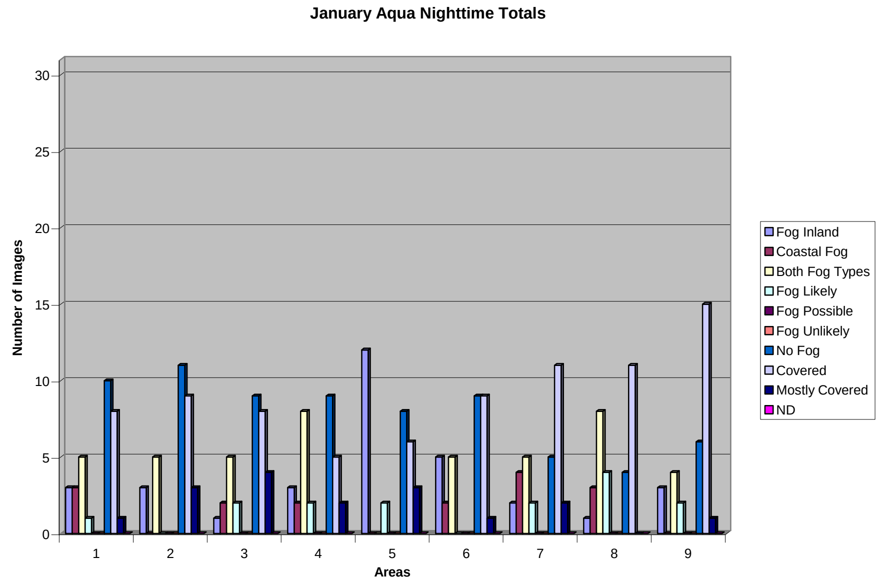

Figure 68. The total number of reports for each category in January for the Aqua nighttime images, in all nine areas of interest.

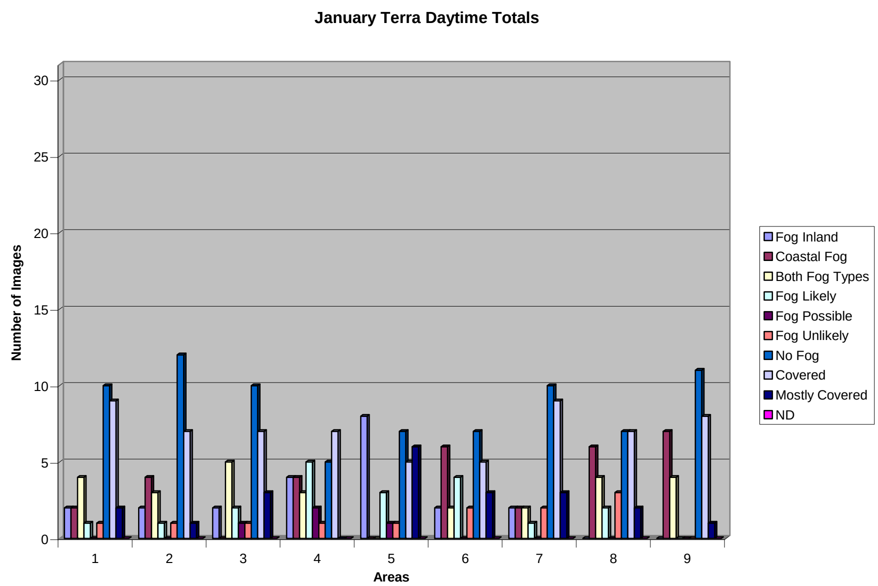

Figure 69. The total number of reports for each category in January for the Terra daytime images, in all nine areas of interest.

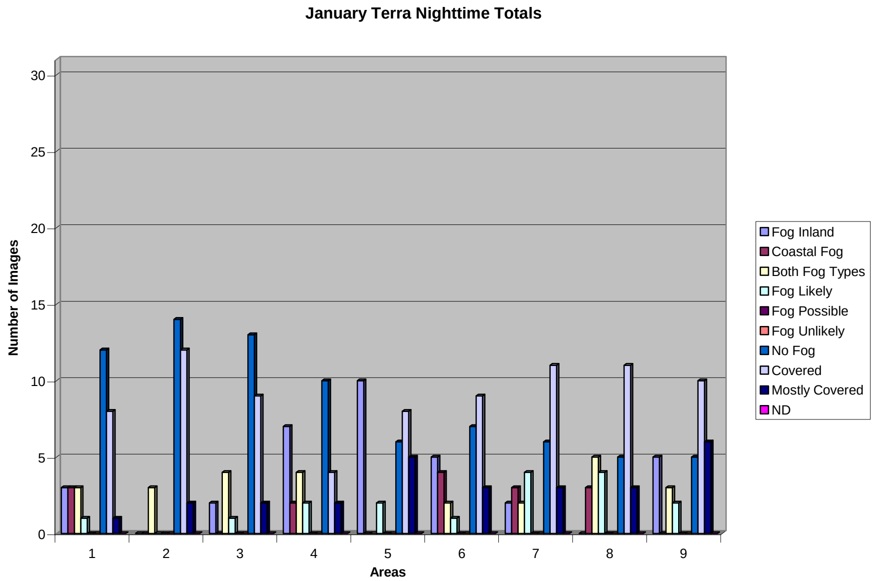

Figure 70. The total number of reports for each category in January for the Terra nighttime images, in all nine areas of interest.

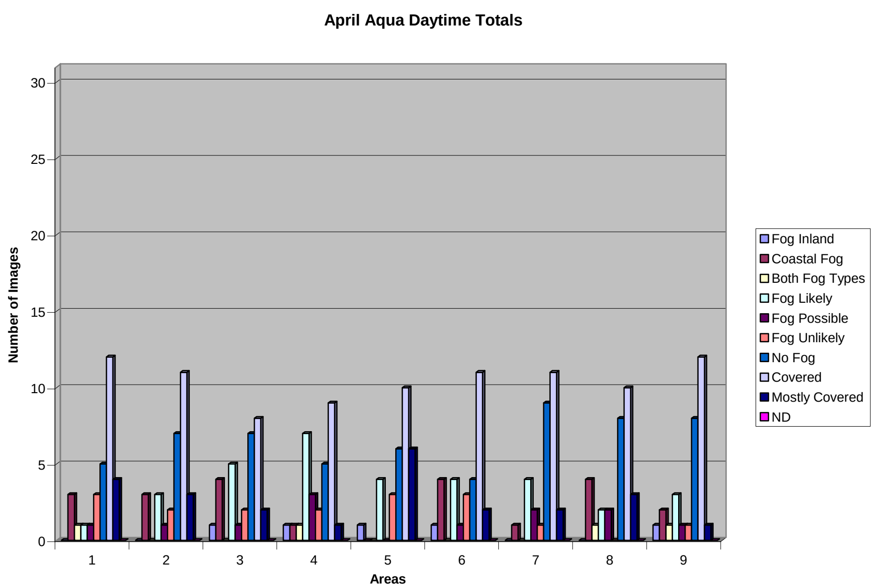

Figure 71. The total number of reports for each category in April for the Aqua daytime images, in all nine areas of interest.

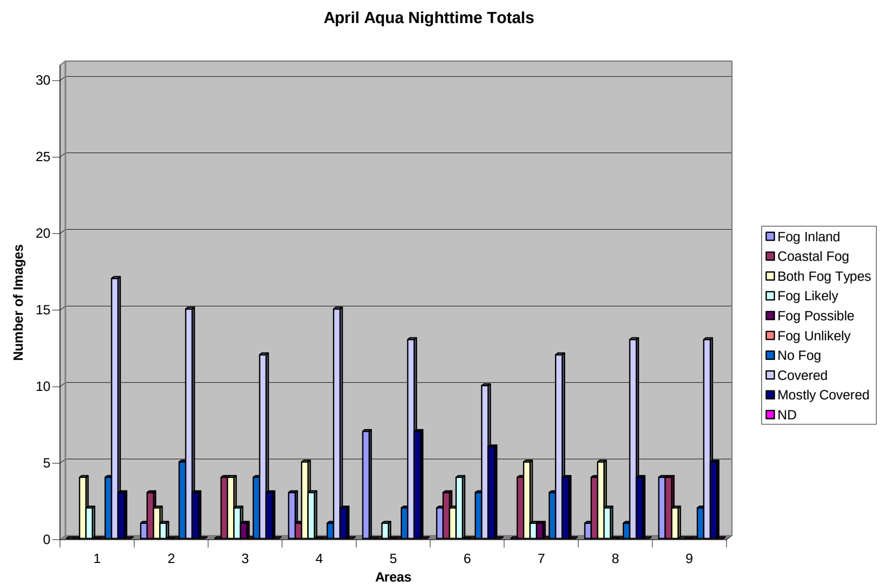

Figure 72. The total number of reports for each category in April for the Aqua nighttime images, in all nine areas of interest.

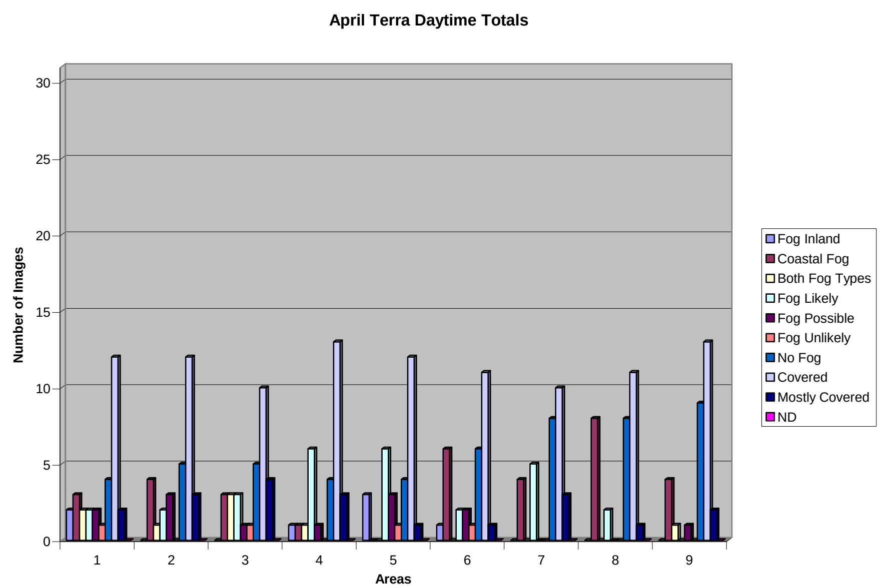

Figure 73. The total number of reports for each category in April for the Terra daytime images, in all nine areas of interest.

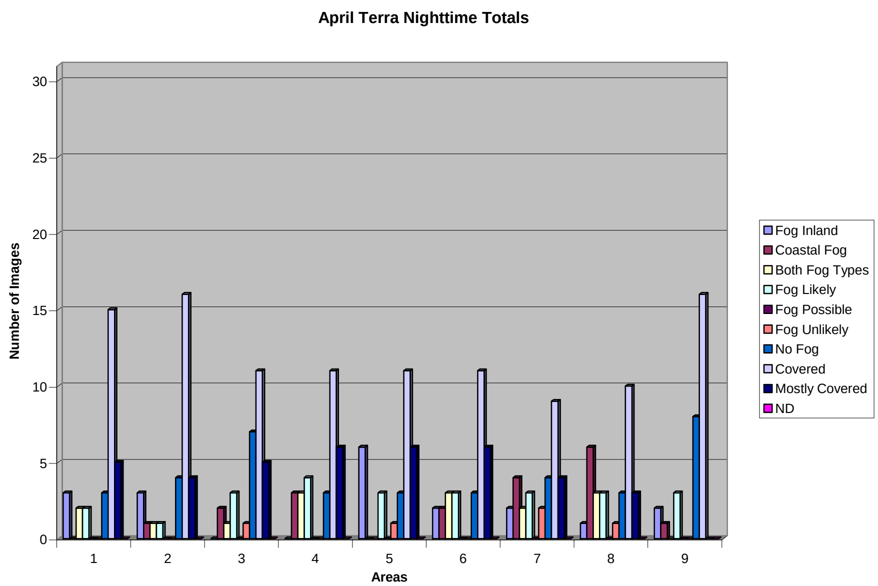

Figure 74. The total number of reports for each category in April for the Terra nighttime images, in all nine areas of interest.

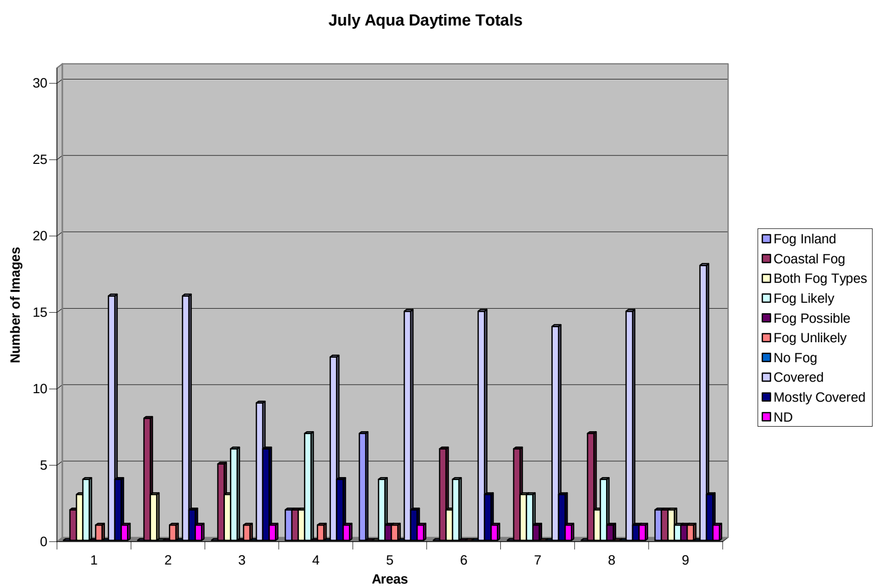

Figure 75. The total number of reports for each category in July for the Aqua daytime images, in all nine areas of interest.

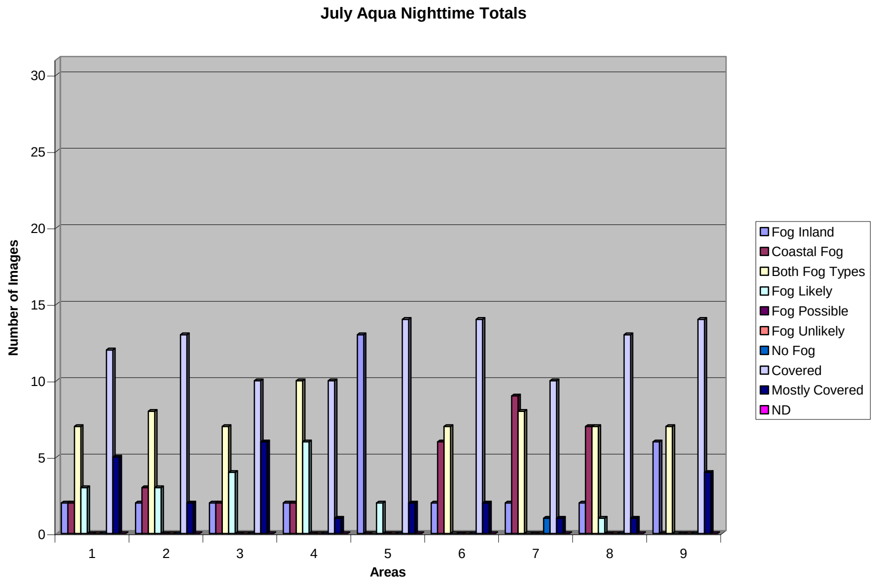

Figure 76. The total number of reports for each category in July for the Aqua nighttime images, in all nine areas of interest.

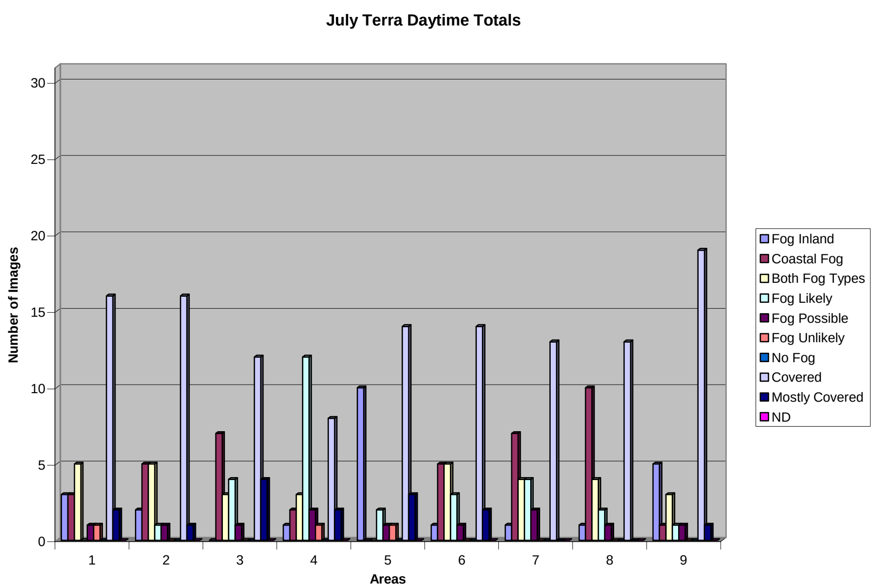

Figure 77. The total number of reports for each category in July for the Terra daytime images, in all nine areas of interest.

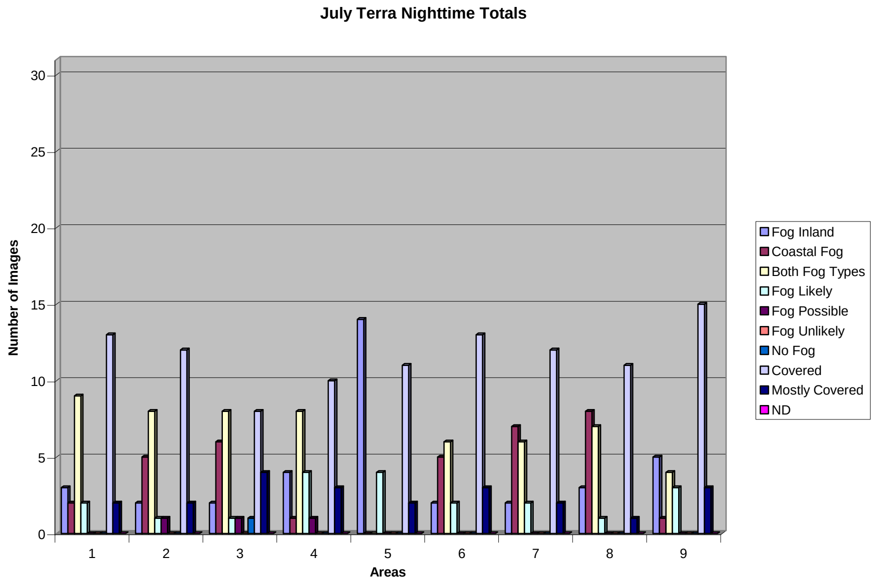

Figure 78. The total number of reports for each category in July for the Terra nighttime images, in all nine areas of interest.

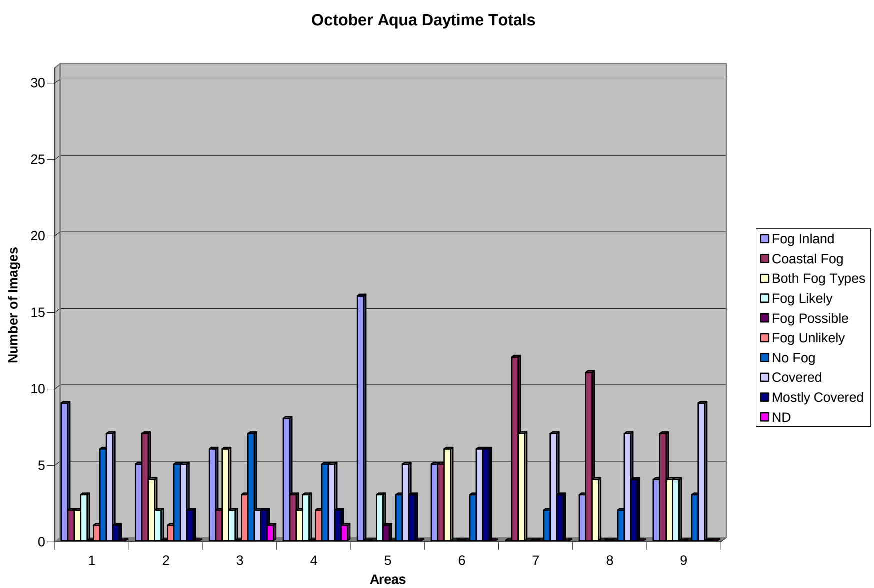

Figure 79. The total number of reports for each category in October for the Aqua daytime images, in all nine areas of interest.

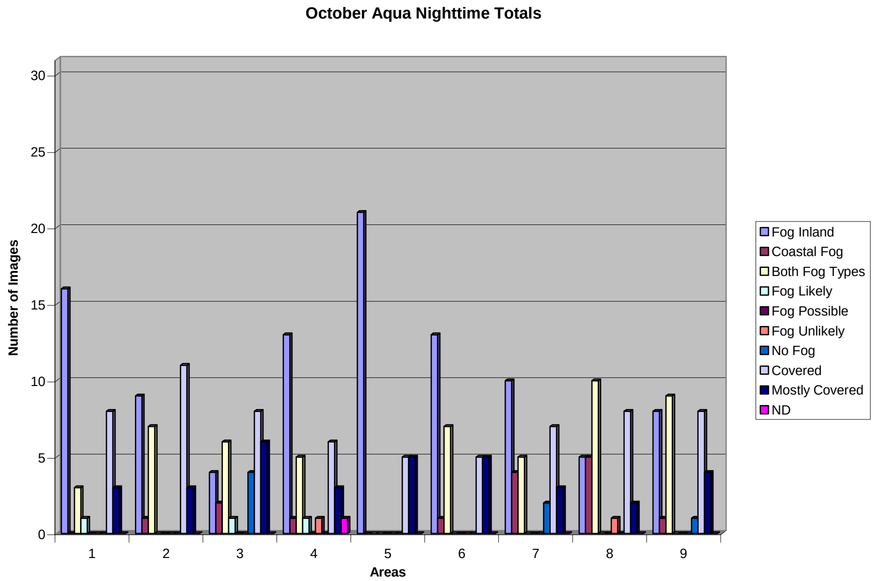

Figure 80. The total number of reports for each category in October for the Aqua nighttime images, in all nine areas of interest.

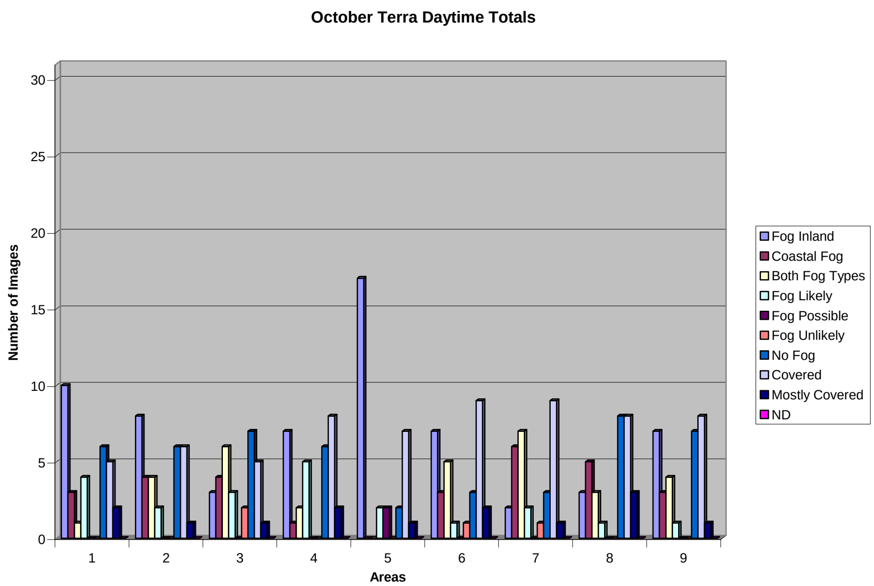

Figure 81. The total number of reports for each category in October for the Terra daytime images, in all nine areas of interest.

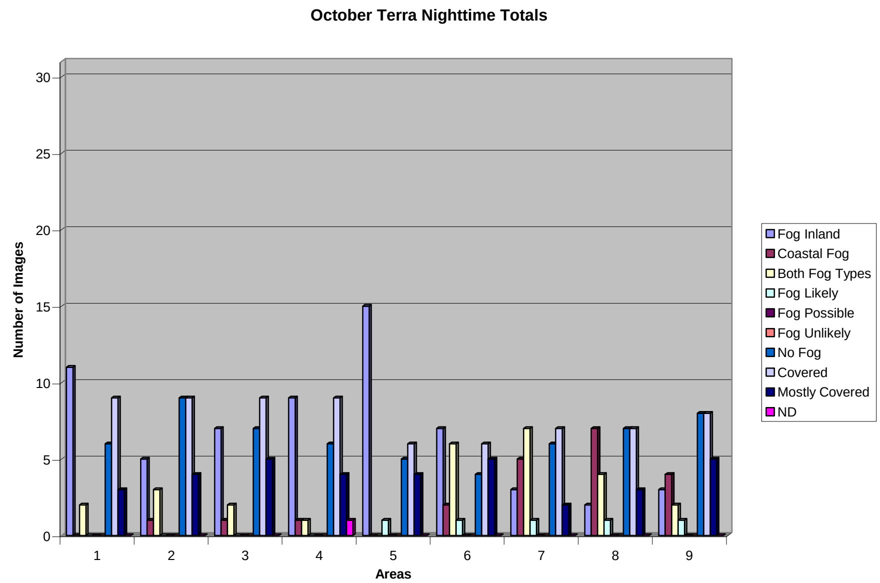

Figure 82. The total number of reports for each category in October for the Terra nighttime images, in all nine areas of interest.

A comparison of the results from this study was made with the other climatology data bases. The monthly fog day charts were used to compare with the monthly mean fog day information used by AFCCC (2007) and the Kim and Lee (1970) study. The Navy study (Guttman 1978) was broken down by four observation times; 00, 06, 12, and 18 UTC, for each month. In order to make a fair comparison, the fog day information for each satellite pass was used which gave results at approximately 0130, 0430, 1330, and 1630 UTC for each month. The data sets from these earlier studies had to be modified to match the nine areas of interest used in this study. Each site was assigned to one of the areas of interest. Since there were only monthly totals given for each location it was not possible to know if the fog at each site occurred on the same days or different days throughout the month. The only way to be fair was to use the maximum value found in each area for a given month. This information was tabulated in a separate spreadsheet as seen in Appendix # and used to produce the bar charts below. Figures 20-23 showed the monthly fog days from this study and Figures 83 and 84 displayed the maximum mean

monthly fog days from AFCCC (2007) and Kim and Lee (1970). The remaining bar charts (see Figures 85-88) compared Guttman (1978) to the results from this study (see Figures 34-41).

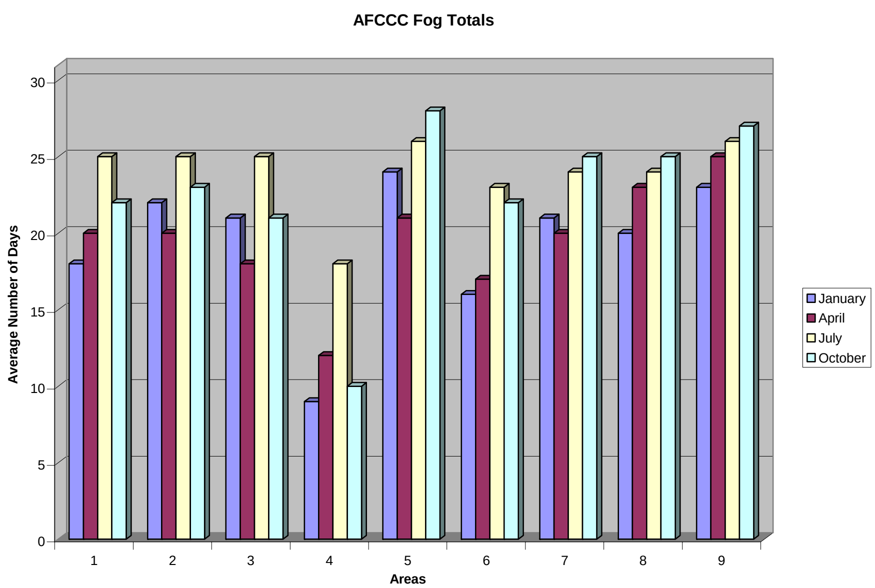

Figure 83. The maximum average number of fog days for all nine areas of interest in each month (after AFCCC 2007).

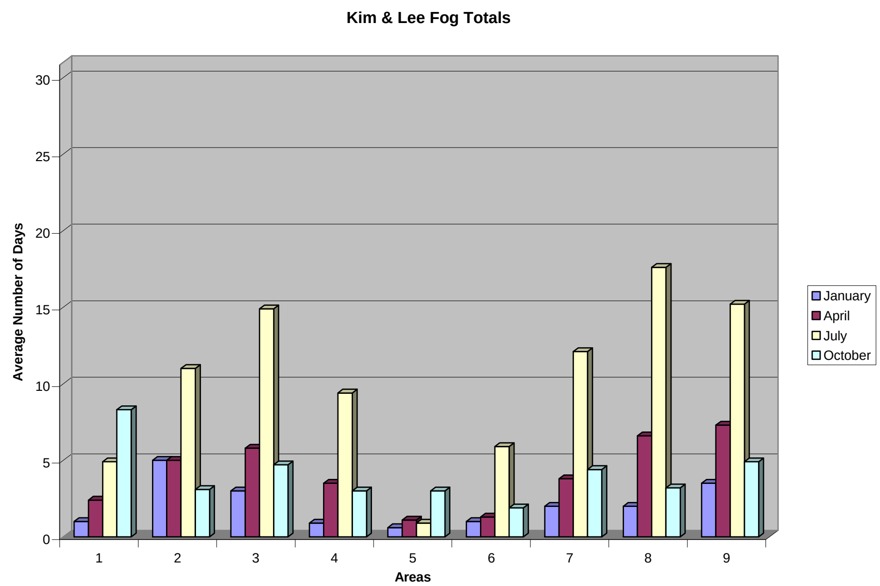

Figure 84. The maximum average number of fog days for all nine areas of interest in each month (after Kim and Lee 1970)

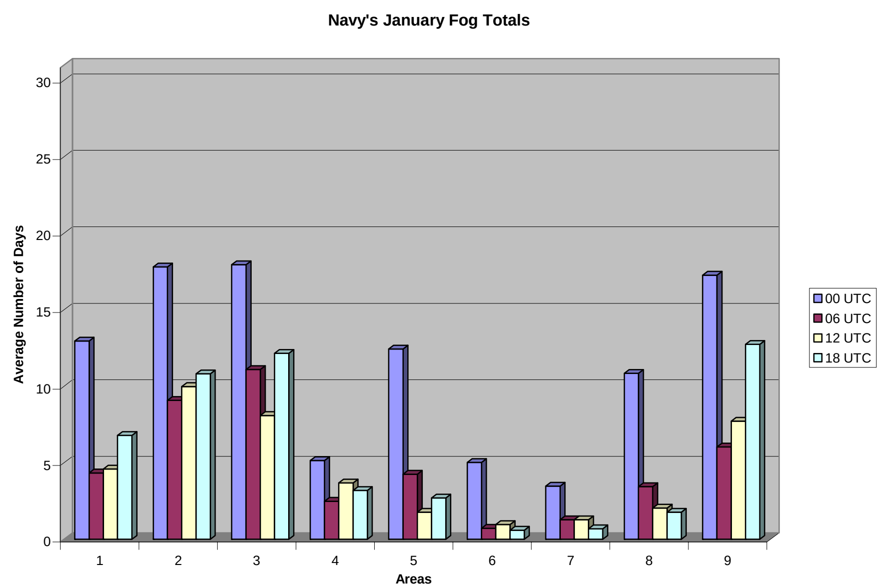

Figure 85. The maximum average number of fog days in January, for each area of interest reported at 00, 06, 12, and 18 UTC (after Guttman 1978).

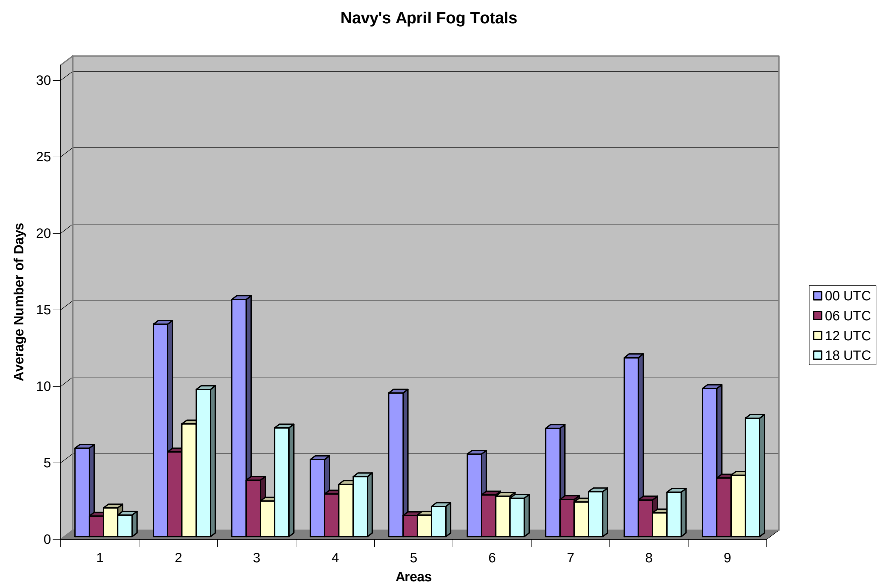

Figure 86. The maximum average number of fog days in April, for each area of interest reported at 00, 06, 12, and 18 UTC (after Guttman 1978).

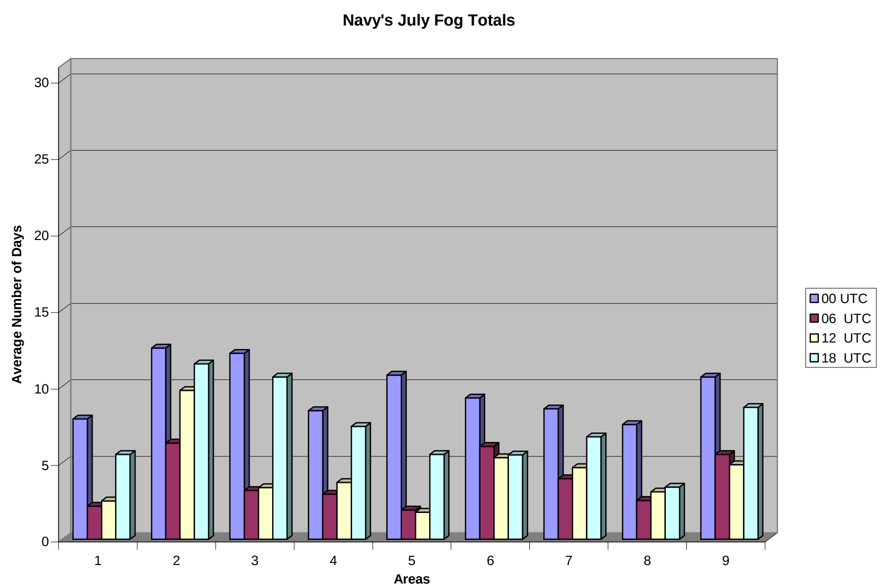

Figure 87. The maximum average number of fog days in July, for each area of interest reported at 00, 06, 12, and 18 UTC (after Guttman 1978).

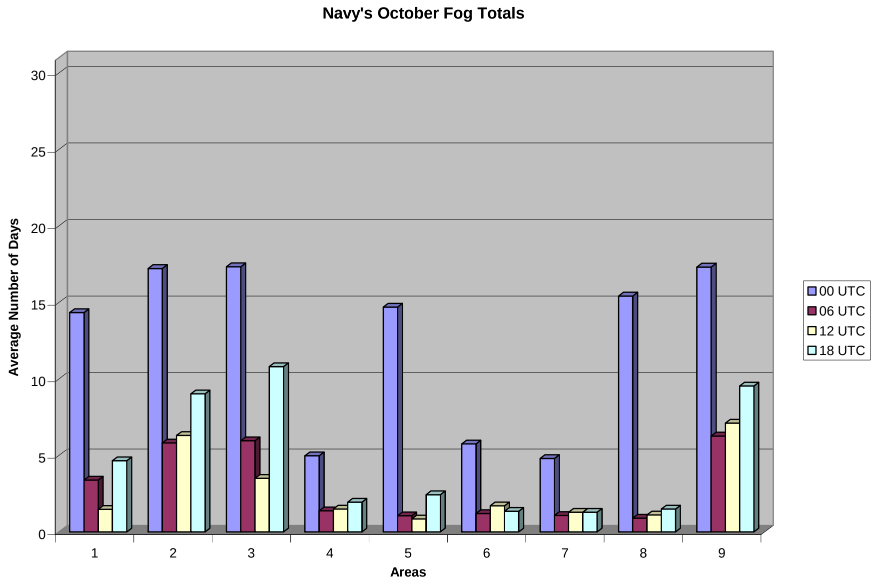

Figure 88. The maximum average number of fog days in October, for each area of interest reported at 00, 06, 12, and 18 UTC (after Guttman 1978).

B. SUMMARY OF RESULTS

The results show distinct diurnal and seasonal variations which were anticipated for this fog study. No significant trends were identified when comparing the two satellites although the number of fog days detected from Aqua is slightly higher than that from Terra in October. One possible reason for this is explained later in this section along with all of the significant trends found in the analysis of results.

The dominant scene for all areas was “covered” by higher cloud (Figures 14-18). When combined with the “mostly covered with higher cloud” category the two provided some interesting results. The nine areas on average were covered for 42 percent of the images over the four month period. Comparisons among the individual areas suggest higher percentage of clouds above the fog layer/surface in the smaller areas (areas one, two, and nine). This is likely caused by the smaller size of these three areas or by the fact that all three are in geographically similar areas in the middle of the peninsula. More information than was available is required to clearly identify the cause. On average 40 percent of the images were covered for January and October while 60 percent were

covered for April and July. This difference between April/July and January/October is reasonable because the more active dynamic weather systems that tend to increase the cloud fraction are found in the months of April and July. The monsoon and typhoon seasons clearly played a significant role in this result.

The fog day totals (see Figures 19-23) produced some expected results but also displayed some surprises. The nine areas averaged 89 fog days for the four month period (see Figure 19), almost 75 percent of the days detectable by satellite. July and October saw about 20 percent more fog days than January and April (see Figures 21-23). Cho et al., 2000, identified a peak in sea fog around Korea in July which could explain the high values for that month. One explanation for the increased fog in October was less dynamic weather occurred, which was conducive for increased radiation fog development (see Figure 23). The individual areas had similar values. Area four had about 12 percent more fog days than the average and the smaller areas one, two, and nine had about 10 percent less. The surprise was area three (west coast of North Korea) which also had about 10 percent fewer fog days than the average but a larger area of coverage than the others (see Figure 19). This was likely due to a number of reasons; according Cho et al., (2000) this area was not favorable for sea fog development. Also, coastal fog due to sea breeze variation was more likely to occur in the southern portions of the peninsula. The more mountainous terrain was seen farther east in area four and was more likely to see valley fog than area three. Synoptic weather patterns could have also played a role in the decreased number of fog days for area three, but a more thorough investigation was needed to clarify these speculations.

There were significant differences in occurrence of daytime and nighttime fog events in the results (Figures 24-28). On average, of all areas considered, the percentage of nighttime fog occurrences is about 32 percent higher than daytime fog (Figure 24). January, April, and July averaged 40 to 50% more nights with fog than days. October only had an 8% increase in nighttime fog reports. This is likely caused, again, by the more relaxed weather patterns and also cooler temperatures during the day which allowed the fog to persist long enough to be detected by the daytime satellite images before dissipating. Comparing results from Terra and Aqua satellites, no systematic differences

are observed except for the month of October (see Figures 29-33). The Aqua results showed considerable increase in fog days compared to those from Terra for all areas of interest. Upon further examination, it was evident that the number of nighttime fog occurrences detected from Aqua images greatly outnumbered those from Terra (see Figure 33). The Terra satellite passes over Korea at about 2230 local time and the Aqua satellite passes over at 0130 local time. This time difference may have been enough for radiation type fog to develop after the Terra satellite passed and then was detected by the Aqua satellite.

When the more detailed charts with all nine categories are examined, it is easy to see that "covered with high cloud" and "fog" reports dominate the totals (see Figures 42-46). There were an increased number of no fog amounts in January and they even exceeded the fog categories during the daytime images. Coastal fog exceeded inland fog for almost every area in each month except October. Inland fog completely dominated the month of October with an average of 64 percent more inland than coastal fog (see Figure 46). Only the two southern coastal areas seven and eight continued to see more coastal fog totals. This evidence supported the earlier argument that the less dynamic synoptic pattern for October was more conducive to radiation type fog instead of advection or coastal fog. April saw the most significant coastal fog domination in the results (see Figure 44). There was an average of 46 percent more coastal fog than inland fog for each area in April. It's important to note that area five was ignored when computing these statistics because it was considered the inner peninsula region and was only awarded inland type fog during the satellite image analysis.

The earlier climatology data sets compared well overall with this study except for the Kim and Lee (1970) data. The mean fog days from the Kim and Lee study (see Figure 84) were extremely low, only the July data showed reasonable totals. The Korean meteorologist that translated this research paper attributed the low numbers to unreliable fog observations before 1970 in Korea. Many stations would only make observations during the daylight hours. The Guttman (1978) data set (see Figures 85-88) compared more closely to this study. Some of the areas had very low totals but this was likely due to the lack of observations available for those areas, plus some questionable older

observations were also used for this data base. The 0000 UTC observation time had the largest total (see Figure 88) and often exceeded the Terra daytime, 0130 UTC totals (see Figures 34-41). This result would indicate that fog might have often dissipated before the Terra made its pass in the morning. AFCCC (2007) totals (see Figure 83) compared much closer to this satellite study than the others. The only real discrepancy was area four which had very low totals in the AFCCC (2007) data set. Again this was likely due to an insufficient amount of observation sites in that area. AFCCC (2007) had a limited number of updated locations available in North Korea and often the data available was from older more questionable observations.

IV. DISCUSSION

A. CONCLUSIONS

The main goals of this thesis were to use satellite imagery to create an abbreviated climatology data set for remote areas across the Korean peninsula and with this data, identify patterns or trends that would help military weather forecasters and planners better understand fog events in Korea. The primary observations used in achieving these goals were MODIS imagery from the Terra and Aqua near-polar orbiting satellites. These NASA satellites typically provided four images per day for this study. Due to time constraints the data set was comprised of the four mid-season months of October 2005 and January, April, and July 2006. The reduced data set limited the analysis capability for the results but the techniques established were as important as the results.

The first task that was completed for this type of study was a break down of possible categories describing different scenes identified from the satellite images. It wasn't always possible to see low clouds or fog and it definitely wasn't always possible to determine if low clouds were fog from a satellite image. This created the need for the different categories. Next, procedures or techniques for identifying the category appropriate for a given image were developed. Two decision trees were constructed to provide a set of guidelines to follow when analyzing an image. One flowchart was for daytime scene detection and the other was for identification at night. Satellite images alone are not enough to guarantee fog detection so it was necessary to collect additional data including surface observations and upper-air data to help confirm if clouds were on the surface. AFCCC (2007) datasets offered extensive coverage for South Korea but only limited sites in North Korea. The number of observations could have been larger with access to the automated sites used by the Korean Meteorological Administration (KMA). With the procedures in place and the tools needed the satellite images were analyzed and the climatology data set was created.

The next goal was to analyze the raw data and identify useful trends or patterns that could help describe the fog characteristics in the region. Hypothesis and other often

used statistical tests were unavailable due to the independent nature of the different fog categories. Hence, the data was tabulated using different variables such as month, daytime, nighttime, Aqua image, Terra image, and specific satellite pass. The totals were converted from spreadsheets to bar charts for better visual comparisons. Finally trends and patterns were annotated in the Results Summary Section.

The results indicated that the dynamic weather patterns in January, April, and July had contrasting affect on fog development compared to the more stagnant weather experienced in October. Coastal fog dominated the types of fog seen in the first three months with a maximum difference in April. October saw 64 percent more fog inland than on the coasts. October and July also had approximately 25 percent more fog days than January and April. For planning purposes based on this study, exercises taking place on the coast should be scheduled for October or the fall season. Events further inland would be better served if planned for April or springtime if fog was the primary concern. Also, for the first three months there was 40 to 50 percent more fog at night than during the daytime which was not abnormal. This wasn't the case for October, which only saw an eight percent increase in nighttime fog over daytime fog. This means fog is lingering longer and could have a greater affect on daytime operations in October. Cloud cover was a major issue for this study. An average of 42 percent of the total images for each area were either covered or mostly covered by higher cloud. This amount was closer to 50 percent during April and July when the monsoon and typhoon seasons became a major factor. For flying operations, visibilities will be impacted most during these months. October had the lowest totals; about 25 percent of the images were covered or mostly covered. This would indicate the best flying weather would be in October or during the fall months, which agrees with the climatology narratives found in AFCCC (2007). The data from this study provided only a small indication of possible patterns in the fog events across the Korean peninsula. More research is needed to confirm these results and to seek more detailed correlations between fog events and the weather patterns causing it.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

This study was the first of its kind for Korea and can be used as the foundation for follow-on research in the future. There were some limitations on this study that need to be overcome in the future. Continuous or almost continuous coverage is recommended to observe the actual onset, dissipation, and duration of the fog at a given location. This means archived high-resolution images from geostationary satellites are needed. Also, it would be beneficial to narrow the focus or reduce the size of the interested areas. The results from this study can help identify high impact areas that can be divided up based on terrain or other influences. Additional tools could be included in the research like the automated observation data from the Korean Meteorological Administration sites, if access is granted to those reports. Also, expanded use of mesoscale model results such as the MASS model used at AFCCC could provide important insight into the mechanisms of fog formation/dissipation.

Finally, continued research is needed to increase the size of the data set so accuracy of the statistics will improve. It would be useful to span several years so effects from large scale oscillations such as El Niño and La Niña would be considered. The results also need to be correlated with the large scale weather patterns to determine any trends that might exist between the synoptic regime and formation or dissipation of fog. With this added information better planning tools could be developed along with possible rules-of-thumb for forecasting fog events.

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APPENDIX A. TABLES OF SATELLITE ANALYSIS RESULTS

The raw data from the satellite image analysis was placed in several spreadsheets, one or each month, satellite used, and time of day. All of the data was included in this Appendix to ensure availability for future work.

Table 3. The raw data from analysis of the January Aqua daytime images. The numbers correspond to the categories given in Table 2.

					JANUARY				
					Aqua				
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Day	6	6	6	7	6	7	7	6	6
2	Day	2	1.2	1.2	1	2	5	5	1.2	1.2
3	Day	5	5	5	5	5	5	5	7	5
4	Day	6	6	7	5	6	6	6	6	6
5	Day	5	5	5	5	5	4	7	7	5
6	Day	5	5	5	3	5	4	6	2	2
7	Day	5	5	5	5	5	5	5	3	5
8	Day	5	5	5	4	5	5	5	5	5
9	Day	5	4	3	3	5	5	4	4	4
10	Day	2	1.1	1.2	1	1	1	1.1	1.1	1
11	Day	5	5	5	2	5	5	7	7	5
12	Day	6	6	6	6	6	6	7	7	6
13	Day	1.2	1.2	1.2	1.2	1	1.1	1.1	1.1	1.1
14	Day	6	1	5	1.1	1	1.1	1.2	1.2	1.2
15	Day	5	5	5	5	6	6	6	6	7
16	Day	6	6	7	2	6	6	6	6	6
17	Day	6	6	6	1.1	7	1.1	7	7	7
18	Day	1.1	5	5	1.1	5	1.1	2	1.1	7
19	Day	1.1	5	5	1.1	2	1.1	6	6	7
20	Day	2	2	5	5	2	2	6	6	7
21	Day	6	7	7	6	6	6	2	2	6
22	Day	5	5	4	4	5	4	4	4	5
23	Day	5	5	5	5	5	5	5	5	5
24	Day	5	5	5	5	5	5	5	5	5
25	Day	4	4	2	3	5	5	5	5	5
26	Day	1	1	1.1	5	1	5	5	1.1	1.1
27	Day	5	1	1	5	1	5	5	1.2	1.2
28	Day	6	6	6	6	7	7	5	4	6
29	Day	6	6	6	6	7	7	2	2	6
30	Day	7	6	6	6	7	7	6	7	6
31	Day	6	1.1	6	6	1	6	6	1.2	1

Table 4. The raw data from analysis of the January Aqua nighttime images.

					JANUARY					
					Aqua					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Night	1.2	1.2	1.2	1.2	1	1.2	1.1	1.1	1
2	Night	1.2	1.2	1.2	1.2	1	1.2	1.2	1.2	1.2
3	Night	2	6	5	2	6	6	6	6	6
4	Night	6	6	6	2	6	6	6	6	6
5	Night	7	7	7	5	7	6	6	6	6
6	Night	5	5	2	5	2	6	6	2	6
7	Night	5	5	5	5	2	5	2	2	2
8	Night	5	5	5	5	5	5	2	2	2
9	Night	5	5	2	5	7	7	7	6	6
10	Night	1.2	1.2	1.2	1.2	1	1	1.2	1.2	1.2
11	Night	5	5	5	1.2	5	5	5	5	5
12	Night	6	6	6	6	5	5	5	5	5
13	Night	6	6	6	6	6	6	6	6	6
14	Night	6	1	1	1	1	1.2	1.2	1.1	6
15	Night	1.2	1.2	6	1.2	1	1.2	1.2	1.2	6
16	Night	1	6	6	6	1	1	1.1	1.2	6
17	Night	1	5	5	5	1	1	1.2	1.2	1
18	Night	1.1	6	6	1.2	6	6	6	6	6
19	Night	1.1	1	7	1.2	1	1.2	6	6	6
20	Night	6	6	1.1	1.1	1	1.1	6	6	6
21	Night	5	7	7	7	5	5	6	6	7
22	Night	5	5	5	5	5	5	5	5	5
23	Night	5	5	5	5	5	5	5	2	5
24	Night	5	5	5	5	1	5	1	1.2	1
25	Night	6	7	1.1	1	6	6	6	6	6
26	Night	1	1	1.2	1	1	1	7	1.2	1.2
27	Night	1.2	1.2	1.2	1.2	1	1	1	1.2	1.2
28	Night	1.1	5	5	1.1	5	1.1	5	1	5
29	Night	5	5	7	7	5	5	1.1	5	5
30	Night	6	6	6	6	7	6	1.1	1.1	6
31	Night	6	6	6	6	6	6	6	6	6

Table 5. The raw data from analysis of the January Terra daytime images.

					JANUARY					
					Terra					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Day	6	6	6	6	6	2	2	6	6
2	Day	1	1.2	1.2	1.2	1	1	1	1.2	1.2
3	Day	5	5	5	2	5	5	5	5	5
4	Day	6	6	7	5	6	6	6	6	6
5	Day	5	5	5	5	5	2	5	5	5
6	Day	5	5	5	3	7	7	6	1.1	1.1
7	Day	5	5	5	2	5	5	5	2	5
8	Day	5	5	5	4	5	5	5	2	5
9	Day	5	4	3	3	4	5	4	4	5
10	Day	1.2	1.2	1.2	1.2	1	1.2	5	5	1.2
11	Day	5	5	5	2	7	7	7	7	6
12	Day	6	6	6	6	7	1.1	6	6	6
13	Day	1.2	1.2	1.2	1.2	2	1.1	6	1.1	1.1
14	Day	7	1.1	2	1.1	1	1.2	1.2	1.2	1.2
15	Day	7	1.1	1	1	6	6	6	6	1.1
16	Day	6	6	6	6	6	6	6	6	6
17	Day	5	5	7	1.1	1	1.1	7	7	7
18	Day	1.1	5	5	1.1	7	1.1	1.1	1.1	6
19	Day	1.1	5	5	1.1	1	1.1	1.2	4	5
20	Day	1.2	1	1	1	2	1.1	6	6	6
21	Day	6	7	6	6	7	6	7	1.1	1.1
22	Day	4	5	4	5	5	4	4	4	5
23	Day	5	5	5	5	5	5	5	5	5
24	Day	5	5	5	5	5	5	5	5	5
25	Day	2	2	2	2	3	4	5	5	5
26	Day	1	1	1.2	1	1	5	5	1.1	1.1
27	Day	1.2	1.1	1.2	1	1	1	1	1.2	1.2
28	Day	6	6	6	6	1	2	5	5	5
29	Day	6	6	6	6	2	2	1.1	1.1	1.1
30	Day	6	6	6	6	7	7	6	6	6
31	Day	6	1.1	7	2	6	6	6	1.2	1.1

Table 6. The raw data from analysis of the January Terra nighttime images.

					JANUARY					
					Terra					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Night	1.2	1.2	1.2	1.2	1	1	1	1.2	1.2
2	Night	2	6	7	2	6	6	6	6	6
3	Night	5	6	6	5	5	5	6	6	7
4	Night	6	6	6	6	6	6	6	6	6
5	Night	5	5	2	5	7	7	6	6	7
6	Night	5	5	5	5	2	5	2	2	2
7	Night	5	5	5	5	5	5	5	2	2
8	Night	5	5	5	5	7	7	7	7	6
9	Night	1.2	1.2	1.2	1.2	2	2	2	2	1.2
10	Night	5	5	5	1	1	1	5	5	5
11	Night	5	5	5	1	5	5	5	5	5
12	Night	6	6	6	6	6	6	6	6	6
13	Night	1	6	1	1	1	1.2	1.2	1.2	6
14	Night	1.1	6	6	1.2	1	1.1	1.2	1.2	1
15	Night	1	5	1.2	1	1	1	1.1	1.2	1
16	Night	6	5	5	7	1	1.1	1.1	1.1	1
17	Night	6	6	6	1	6	6	6	6	7
18	Night	1.1	6	7	1.2	1	1.2	6	6	7
19	Night	6	6	6	1.1	6	6	6	6	6
20	Night	7	7	5	7	7	6	6	7	7
21	Night	5	5	5	5	5	1.1	1.1	5	5
22	Night	5	5	5	5	5	5	5	5	5
23	Night	5	5	5	5	1	5	5	1.1	1
24	Night	5	5	5	5	7	5	7	7	7
25	Night	1.2	7	1	1	1	1	7	1.1	1
26	Night	1	1.2	1.2	1	1	1	1	1.2	1.2
27	Night	1.1	5	5	1.1	5	1.1	5	5	5
28	Night	5	5	5	5	6	6	2	6	6
29	Night	6	6	6	2	7	7	2	2	6
30	Night	6	6	6	6	6	6	6	6	6
31	Night	6	6	6	6	6	6	6	6	6

Table 7. The raw data from analysis of the April Aqua daytime images.

					APRIL					
					Aqua					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Day	6	6	2	2	6	6	6	6	6
2	Day	7	1.1	2	1.1	6	6	2	1.2	1.2
3	Day	5	5	5	5	5	5	5	5	5
4	Day	7	1.1	1.1	7	6	6	6	6	6
5	Day	3	3	5	5	2	1.1	3	3	3
6	Day	6	6	6	6	6	6	6	6	6
7	Day	7	7	1.1	3	7	2	2	2	2
8	Day	5	5	5	5	5	5	5	5	5
9	Day	1.1	6	6	2	7	1.1	6	6	7
10	Day	6	6	5	6	6	6	6	6	6
11	Day	6	1.1	1.1	1	6	6	6	6	6
12	Day	1.1	7	7	6	2	1.1	2	7	2
13	Day	6	6	2	2	6	6	6	6	6
14	Day	5	5	5	5	5	2	2	2	5
15	Day	6	2	2	2	6	6	6	6	6
16	Day	4	5	5	5	5	4	5	5	5
17	Day	6	6	3	3	4	4	5	5	6
18	Day	6	2	6	6	7	2	7	7	2
19	Day	6	6	6	6	6	6	6	6	6
20	Day	6	6	7	6	6	6	7	7	6
21	Day	1.2	5	1	1.2	1	1	5	5	5
22	Day	5	5	2	2	7	7	6	1.1	5
23	Day	1.1	6	6	6	2	1.1	5	1.1	1
24	Day	4	4	4	4	4	4	5	5	5
25	Day	5	5	5	3	5	5	5	5	5
26	Day	7	7	6	6	7	6	6	6	6
27	Day	4	4	4	4	4	3	3	3	4
28	Day	6	6	6	6	5	5	4	1.1	1.1
29	Day	2	2	1.1	2	2	2	1.1	1.1	1.1
30	Day	6	6	6	2	7	7	5	5	6

Table 8. The raw data from analysis of the April Aqua nighttime images.

					APRIL					
					Aqua					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Night	2	1.1	1.2	1.2	7	2	6	6	1.2
2	Night	6	1.1	1.1	6	6	1.1	1.1	6	1
3	Night	1.2	1.2	1.2	1.2	1	1	1.1	1.2	1.2
4	Night	6	6	6	6	6	6	6	6	6
5	Night	6	7	6	6	6	6	6	6	6
6	Night	1.2	6	6	1.1	1	1.2	6	6	7
7	Night	6	6	6	6	1	6	1.2	1.1	1.1
8	Night	2	5	3	2	1	2	3	1.1	1.1
9	Night	6	6	6	6	6	6	6	6	6
10	Night	6	6	6	6	6	6	6	6	6
11	Night	6	1.1	1.2	1.2	6	6	6	6	6
12	Night	1.2	5	5	1.2	1	1.2	1.2	1	1
13	Night	6	6	2	2	6	6	6	6	6
14	Night	6	6	6	6	2	1.1	1.1	1.1	6
15	Night	6	6	6	6	6	2	2	7	6
16	Night	7	2	7	2	7	7	7	7	7
17	Night	7	7	7	6	5	5	5	2	7
18	Night	6	6	6	6	7	7	7	7	7
19	Night	6	6	6	6	6	2	6	2	6
20	Night	6	6	6	6	6	6	6	6	6
21	Night	5	5	5	7	7	7	7	5	5
22	Night	7	6	2	6	6	6	6	6	7
23	Night	5	1.2	1.2	1.2	1	1.1	1.2	7	1
24	Night	1.2	1	5	1	1	1	5	1.2	1
25	Night	5	5	5	5	5	5	5	1.2	5
26	Night	6	7	7	6	6	6	6	6	6
27	Night	6	6	1.1	1	7	7	1.2	1.2	6
28	Night	5	5	1.1	1	7	5	7	1.1	1.1
29	Night	6	6	1.1	7	6	7	1.1	6	6
30	Night	6	6	6	6	7	7	1.2	1.2	1.1

Table 9. The raw data from analysis of the April Terra daytime images.

					APRIL					
					Terra					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Day	6	6	6	6	6	6	6	6	6
2	Day	6	6	2	1.1	6	1.1	2	1.1	1.2
3	Day	1	1.1	1.1	5	1	5	5	5	5
4	Day	6	6	6	6	6	6	6	6	6
5	Day	2	2	5	2	2	1.1	2	2	5
6	Day	6	6	6	6	6	6	6	6	6
7	Day	3	3	1.2	7	3	3	2	1.1	3
8	Day	5	5	4	5	5	5	5	5	5
9	Day	1.1	7	1.1	2	2	1.1	7	1.1	7
10	Day	6	6	2	6	6	6	6	6	6
11	Day	6	1.1	1.1	2	6	6	6	6	6
12	Day	1	3	7	6	2	1.1	1.1	1.1	5
13	Day	6	6	6	6	6	6	6	6	6
14	Day	5	5	5	5	5	2	2	1.1	5
15	Day	6	6	7	7	6	6	6	6	6
16	Day	4	5	5	5	4	4	5	5	5
17	Day	6	6	6	6	3	3	5	5	7
18	Day	1.1	6	2	2	7	1.1	7	7	6
19	Day	6	6	6	6	6	6	6	6	6
20	Day	6	6	7	6	6	7	7	6	6
21	Day	1.2	5	5	1.2	1	1	5	5	5
22	Day	5	7	7	7	6	6	6	6	6
23	Day	1.1	1.1	6	6	2	5	5	1.1	1.1
24	Day	3	3	3	3	3	5	5	5	5
25	Day	5	5	5	2	5	5	5	5	5
26	Day	7	7	6	6	6	6	6	6	6
27	Day	2	2	1.2	1	2	2	2	2	1.1
28	Day	7	1.1	6	6	5	5	1.1	1.1	1.1
29	Day	1.2	1.2	1.2	2	2	6	1.1	1.1	1.1
30	Day	6	6	6	6	1	1.1	1.1	5	6

Table 10. The raw data from analysis of the April Terra daytime images.

					APRIL					
					Terra					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Night	6	6	6	6	6	6	6	6	6
2	Night	1	1	5	1.1	1	1.2	5	1.2	1.1
3	Night	6	6	7	7	6	6	7	6	6
4	Night	6	6	6	6	6	6	6	6	6
5	Night	1.2	5	5	1.1	1	1.2	1.2	7	5
6	Night	6	6	6	6	2	6	2	2	2
7	Night	7	1.1	7	7	1	7	1.1	1.2	1
8	Night	6	6	6	6	6	6	6	6	6
9	Night	6	6	6	6	6	6	6	6	6
10	Night	6	6	6	1.2	6	6	6	6	6
11	Night	1.2	1	5	1.2	1	1.2	1.2	1.2	5
12	Night	6	6	2	2	6	6	6	6	6
13	Night	6	6	6	1.1	2	2	1.1	1.1	6
14	Night	7	7	7	7	6	6	6	6	6
15	Night	7	7	2	2	5	5	5	5	5
16	Night	5	7	4	5	5	5	2	5	5
17	Night	2	2	2	2	4	2	4	4	2
18	Night	6	6	6	6	6	1.1	1	2	6
19	Night	6	6	6	6	7	7	4	7	6
20	Night	7	7	5	7	7	7	7	5	5
21	Night	7	6	6	7	7	7	6	6	6
22	Night	1	1.2	1.2	1.2	1	1.1	1	1.1	5
23	Night	2	5	5	2	2	2	2	2	2
24	Night	5	5	5	5	5	5	5	1	5
25	Night	6	6	7	6	6	6	6	6	6
26	Night	6	6	6	6	7	7	7	7	1
27	Night	5	5	1.1	5	7	1	7	1.1	6
28	Night	6	6	7	6	6	6	5	1.1	6
29	Night	6	6	1.1	6	7	7	1.1	1.1	6
30	Night	1	1	5	7	1	1	1.1	1.1	5

Table 11. The raw data from analysis of the July Aqua daytime images.

					JULY					
					Aqua					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Day	6	6	7	6	6	6	6	6	6
2	Day	7	4	4	6	7	7	7	6	4
3	Day	4	1.1	1.1	4	4	1.1	1.1	1.1	1.1
4	Day	6	6	6	6	6	6	6	6	6
5	Day	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	Day	6	6	7	7	6	6	6	6	6
7	Day	2	1.1	1.1	2	1	1.1	1.1	1.1	1
8	Day	7	7	1.1	1.1	6	6	6	6	6
9	Day	2	1.1	2	2	6	6	6	1.1	1.1
10	Day	6	6	2	2	6	6	6	6	6
11	Day	7	7	7	7	6	6	6	6	6
12	Day	6	6	7	7	1.2	1.2	1.2	1.2	1.2
13	Day	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
14	Day	6	6	6	6	2	1.1	2	1.1	7
15	Day	6	6	6	6	7	7	7	7	7
16	Day	6	6	2	6	6	6	1.1	1.1	6
17	Day	6	6	6	2	6	6	6	6	6
18	Day	6	6	6	6	6	6	6	6	6
19	Day	1.1	1.1	1.1	1	6	6	6	6	6
20	Day	7	6	7	6	6	6	6	6	6
21	Day	1.2	1.2	1.2	1.2	1.2	1.1	1.1	6	6
22	Day	2	1.1	2	2	2	2	1.1	1.1	7
23	Day	1.2	1.2	2	2	6	6	6	6	6
24	Day	6	6	7	7	6	6	6	6	6
25	Day	1.1	1.1	2	2	1	2	7	2	6
26	Day	6	6	6	6	6	6	6	6	6
27	Day	6	6	6	6	1	1.1	1.1	2	6
28	Day	6	6	1.2	1	1	7	1.2	1.1	6
29	Day	2	1.1	1.1	1.1	2	2	2	2	1
30	Day	6	1.1	6	6	2	2	2	2	2
31	Day	6	6	6	6	3	1.1	3	3	3

Table 12. The raw data from analysis of the July Aqua nighttime images.

					JULY					
					Aqua					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Night	2	2	2	2	6	6	6	6	6
2	Night	7	1	7	6	1	1	1	1	1
3	Night	1	1	1	1	1	1	1	1	1
4	Night	6	6	6	6	6	1.1	1.1	6	6
5	Night	7	1.1	2	2	6	6	6	6	6
6	Night	2	2	6	1	2	7	1.1	6	1
7	Night	6	6	6	6	6	6	1.1	1.1	1
8	Night	1.2	1.2	1.2	1.2	1.2	1.2	1.2	6	1.2
9	Night	1.2	1.2	1.2	1.2	6	6	6	6	1.2
10	Night	7	7	7	2	6	6	6	6	6
11	Night	2	2	7	2	2	1.1	1.1	2	7
12	Night	7	1.1	2	2	7	7	6	6	6
13	Night	1.2	1.2	1.2	1.2	1.2	1.2	7	1.2	1.2
14	Night	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
15	Night	6	6	6	6	1	6	1.1	1.2	7
16	Night	6	6	6	6	1.2	1.2	1.2	1.2	7
17	Night	6	6	6	6	6	6	1.1	1.1	6
18	Night	6	6	6	6	6	6	6	6	6
19	Night	6	6	2	2	6	6	6	6	6
20	Night	1.1	1.1	1.1	1.1	1	1.1	6	6	6
21	Night	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
22	Night	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
23	Night	1.2	1.2	1	1.2	1	1.2	1.2	6	1
24	Night	6	6	7	1.2	6	6	6	6	7
25	Night	7	7	7	7	6	6	6	7	6
26	Night	6	6	6	6	6	6	1.1	1.1	6
27	Night	6	6	6	6	1	1.1	1.2	1.1	6
28	Night	1.1	6	7	1.1	1	1.1	1.2	1.1	1
29	Night	1	1.2	1.2	1.2	6	6	1.1	1.1	6
30	Night	6	6	6	1.2	7	1.1	5	1.1	6
31	Night	6	6	1.1	6	6	6	1.1	1.2	1.2

Table 13. The raw data from analysis of the July Terra daytime images.

					JULY					
					Terra					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Day	6	6	6	6	6	6	6	6	6
2	Day	1	1	1.1	2	1	1	1	1	1
3	Day	4	1.1	1.1	4	4	1.1	1.1	1.1	1.1
4	Day	6	6	6	6	6	6	6	6	6
5	Day	7	2	2	7	7	7	2	1.1	2
6	Day	6	6	7	7	6	6	6	6	6
7	Day	1.1	1.1	1.1	1.1	1	1.1	1.1	1.1	1
8	Day	6	6	1.1	2	6	6	6	6	6
9	Day	1.1	1.1	1.1	1.1	7	1.1	1.1	1.1	6
10	Day	6	6	2	2	6	6	6	6	6
11	Day	3	3	3	3	6	6	6	6	7
12	Day	6	6	7	3	1.2	1.2	1.2	1.2	1.2
13	Day	7	1.1	1.1	2	2	1.1	2	1.1	1
14	Day	6	6	6	6	3	3	3	1.1	3
15	Day	6	6	6	6	6	6	6	6	6
16	Day	6	6	6	2	6	6	1.1	1.1	6
17	Day	6	6	6	2	6	6	6	6	6
18	Day	6	6	6	6	6	6	6	6	6
19	Day	1	1.1	1.1	1	6	6	6	6	6
20	Day	1.1	7	6	2	7	7	6	6	6
21	Day	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
22	Day	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1
23	Day	1.2	1.2	2	2	6	6	6	6	6
24	Day	6	6	7	2	6	6	6	6	6
25	Day	1.2	1.2	2	2	1	2	2	2	6
26	Day	6	6	6	6	6	6	1.1	1.1	6
27	Day	6	6	6	6	1.1	1.2	1.2	1.2	6
28	Day	6	6	7	2	1	1.2	1.2	1.2	1
29	Day	1.2	1.2	1.2	1.2	1	1.1	1.1	1.1	6
30	Day	1	1	6	6	1	2	2	2	6
31	Day	6	6	6	2	2	2	3	3	1.2

Table 14. The raw data from analysis of the July Terra nighttime images.

					JULY					
					Terra					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Night	6	6	1.1	6	2	6	2	1	2
2	Night	1	1	1	1	1	1	1	1	1
3	Night	6	6	6	6	6	6	6	6	6
4	Night	2	1.1	1.1	2	2	2	6	6	2
5	Night	2	1.1	1.1	2	2	1.1	1.1	1.1	7
6	Night	6	6	6	6	6	6	1.1	1.1	1
7	Night	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
8	Night	1.2	1.2	1.2	1.2	6	6	6	6	6
9	Night	1.1	2	1.1	1.2	2	1.1	6	7	2
10	Night	7	1.1	7	7	1.2	1.2	1.2	1.2	7
11	Night	7	3	3	3	6	6	6	6	6
12	Night	1.2	1.2	1.2	1.2	1.2	1.2	7	1.2	1.2
13	Night	1.2	1.2	1.2	1.2	1.2	1.2	7	1.1	7
14	Night	6	6	6	6	1	7	1.1	1.1	1
15	Night	6	6	6	6	1	6	1.1	1.1	1
16	Night	6	6	6	1	6	6	6	6	6
17	Night	6	6	6	6	6	6	6	6	6
18	Night	6	6	2	2	6	6	6	6	6
19	Night	1	1.1	1.1	1	6	6	6	6	6
20	Night	1	1.1	1.1	1	1	1.1	1.1	1.1	1
21	Night	1.2	1.2	1.2	6	1.2	1.2	1.2	1.2	1.2
22	Night	1.2	1.2	5	1.1	1	1.1	1	1	1.1
23	Night	6	6	7	2	6	6	6	6	6
24	Night	6	7	7	7	6	6	6	6	6
25	Night	6	6	6	6	6	6	6	6	6
26	Night	6	6	6	6	7	7	1.1	1.1	6
27	Night	6	7	7	7	1	7	1.1	1.1	6
28	Night	1.2	6	1.2	1.2	7	1.1	1.2	1.2	6
29	Night	1.2	1.2	1	1.2	1	1	1.2	1.2	6
30	Night	1.1	1	1.2	6	1	2	2	2	6
31	Night	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

Table 15. The raw data from analysis of the October Aqua daytime images.

					OCTOBER					
					Aqua					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Day	1.1	1.1	1.2	1.2	6	7	1.1	1.1	1.1
2	Day	4	4	4	4	2	7	1.1	1.1	2
3	Day	2	2	2	2	1	1.1	1.1	7	6
4	Day	5	5	4	5	6	6	6	6	6
5	Day	6	6	1	1	7	7	6	6	6
6	Day	5	7	7	7	1	1.2	1.1	7	1.1
7	Day	6	6	6	6	6	6	6	6	6
8	Day	1.2	1.2	5	1	1	1.2	1.2	1.2	1.2
9	Day	6	1.1	1.1	6	1	6	1.1	1.1	1.1
10	Day	2	1	1.2	1	1	1.2	1.2	1.1	2
11	Day	1	1.2	1.2	1.1	1	1.2	1.2	1	1
12	Day	5	5	7	1.1	1	1.1	1.1	1.1	5
13	Day	6	6	6	6	1	1.2	1.2	1.2	6
14	Day	5	5	5	5	6	6	6	6	5
15	Day	1	1.1	2	2	1	1	1.1	1.2	1.2
16	Day	5	1.1	4	4	3	5	5	5	1.1
17	Day	1	1.2	1.2	1.2	5	5	5	5	1.1
18	Day	1	1	1	6	1	1	1.1	1	1
19	Day	1	1	5	1	2	7	1.1	1.1	2
20	Day	1	1.1	5	5	1	1	1.1	1.1	2
21	Day	6	1.1	1	1	6	6	6	6	6
22	Day	1	5	5	5	5	1.1	1.1	1.1	5
23	Day	1	5	5	5	5	5	7	1.1	1
24	Day	2	2	1.2	1	1	1	1.2	1.2	1.2
25	Day	1.1	1	1.1	1.1	2	1.1	6	6	6
26	Day	1.2	1.2	ND	ND	1	1.1	1.1	1	1.1
27	Day	6	6	1	6	1	1	1.2	1.1	1.2
28	Day	1	1.1	1.2	1	1	6	6	6	1
29	Day	7	6	1	2	7	7	7	7	6
30	Day	6	7	5	7	7	7	7	7	6
31	Day	5	1	1	1	1	1.2	1.2	1.1	1.1

Table 16. The raw data from analysis of the October Aqua nighttime images.

					OCTOBER					
					Aqua					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Night	7	6	6	6	6	7	7	7	6
2	Night	6	6	6	6	1	1	1.2	1.2	6
3	Night	6	6	7	6	7	1.1	1.1	1.1	6
4	Night	6	6	1.1	1	6	6	6	6	6
5	Night	1	6	1	1	1	1	6	6	1
6	Night	1	1	1.2	1	1	1	1	1.2	1
7	Night	6	6	6	6	6	6	6	6	6
8	Night	1.2	1.2	1.2	1.2	1	1.2	1.2	1.2	1.2
9	Night	1.2	1.2	5	1.2	1	1.2	1	1	1.2
10	Night	1	1	5	1	1	1.2	1.1	1.1	1
11	Night	1	1	1	1.2	1	1.2	1.2	1.2	1.2
12	Night	1	6	6	1	1	1.2	1.2	1	1.1
13	Night	1	1.2	1.1	1.1	1	1.2	1.2	1.2	1.2
14	Night	2	6	6	7	1	7	1.1	1.1	7
15	Night	6	6	2	2	6	6	1.1	6	6
16	Night	1	1	1	1	1	1	5	1.1	1
17	Night	1	1	1.2	1	1	1	1	1	1
18	Night	1.2	1.2	5	1.2	1	1	1	1.2	1.2
19	Night	1	1.1	1	1	1	1	1	1	1.2
20	Night	1	1	6	1	1	1	1	1.2	1
21	Night	6	6	6	6	7	1	6	6	6
22	Night	6	7	7	7	7	6	7	7	7
23	Night	1	1	5	ND	1	1	5	1.1	5
24	Night	1	1.2	1.2	1	1	1	1	1.2	1.2
25	Night	1	1.2	1.2	4	1	1	6	6	1.2
26	Night	1	7	7	1.2	1	1.2	1	1.2	1
27	Night	1	1.2	1.2	1	1	1	1	1.2	1.2
28	Night	6	6	6	6	6	6	6	6	6
29	Night	7	7	7	7	7	7	6	6	7
30	Night	7	1	7	1	7	7	7	4	7
31	Night	1	1	7	1	1	7	1	1	1

Table 17. The raw data from analysis of the October Terra daytime images.

					OCTOBER					
					Terra					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Day	1.1	2	1.2	1.2	2	7	2	2	1.1
2	Day	2	2	5	2	7	6	1.1	1.1	1
3	Day	7	7	7	6	1	1.1	1.1	7	6
4	Day	5	5	5	5	6	6	6	6	6
5	Day	6	6	6	6	6	6	6	6	6
6	Day	1	1	1.1	7	1	1.2	1.1	5	5
7	Day	6	6	6	6	6	6	6	6	6
8	Day	1.2	1.2	1	1	1	1.2	1.2	1.2	1.2
9	Day	7	1.1	2	2	1	6	1	1	1
10	Day	1	1	1	1	1	1.2	1.1	7	5
11	Day	2	1	2	2	1	1.2	1.2	1	5
12	Day	1	1	1.1	1.1	1	1.2	1.2	1.1	5
13	Day	2	6	6	7	1	1	1.2	1.2	1
14	Day	5	5	5	5	6	6	6	6	6
15	Day	1	1.1	1.2	1	1	2	5	5	1.1
16	Day	5	1.1	4	5	3	5	5	5	1.1
17	Day	1	1	1.2	1	5	5	5	5	5
18	Day	1	1	1	6	1	1	1.1	1	1
19	Day	1	1	5	1	1	1	1.2	5	1
20	Day	1	1.1	5	5	1	1.1	2	1.1	1
21	Day	6	6	6	6	6	6	6	6	6
22	Day	2	5	5	1	1	1	1.1	1.1	5
23	Day	5	5	5	5	1	1	6	1.1	1.2
24	Day	1	1	1.2	1	1	1	1.2	1.2	1.2
25	Day	1.1	1.2	1.2	2	2	1.1	6	6	1
26	Day	1.1	1.2	1.1	1.2	1	7	1	5	2
27	Day	1	1.2	1.2	6	1	1	1.2	5	1.2
28	Day	6	6	6	6	6	6	6	6	6
29	Day	5	5	2	2	3	5	7	7	7
30	Day	6	6	4	6	6	6	6	6	6
31	Day	5	5	1.1	5	5	4	4	5	5

Table 18. The raw data from analysis of the October Terra nighttime images.

					OCTOBER					
					Terra					
		Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
1	Night	7	7	7	7	2	2	2	2	7
2	Night	6	6	6	6	7	7	1.1	1.1	6
3	Night	6	6	6	6	6	6	1	6	6
4	Night	6	6	7	5	1	1	6	6	1
5	Night	1	5	1	5	1	1	1.2	1.2	5
6	Night	6	6	6	6	6	6	6	6	6
7	Night	6	6	6	6	6	6	6	6	6
8	Night	1.2	1	1	1.2	1	1.2	1.2	1.1	5
9	Night	1	1.1	5	1	1	1	1.1	1.1	1.1
10	Night	1	1	5	5	1	1.1	1.1	1.1	2
11	Night	1	7	6	1	1	1.2	1.2	5	5
12	Night	1	1	7	1	1	1.2	1.2	1.2	7
13	Night	6	6	6	6	6	6	6	6	6
14	Night	6	6	1.1	6	6	1.1	1.1	7	6
15	Night	1	5	1	5	1	1	5	5	1
16	Night	5	5	1	7	5	7	5	5	5
17	Night	1.2	1.2	5	1.1	1	1	5	1	1.2
18	Night	1	1	1	1	1	1.2	1.2	5	1
19	Night	1	1	5	1	1	1.2	1	1.2	1.2
20	Night	7	7	6	6	5	1	1.2	5	5
21	Night	6	6	6	6	6	6	6	6	6
22	Night	5	5	5	5	5	5	5	1.1	5
23	Night	5	5	1	1	1	7	7	1.1	1.1
24	Night	1	1.2	1.2	5	5	5	1.1	5	5
25	Night	1	7	7	1	1	1.2	6	1	7
26	Night	5	1.2	1.2	ND	1	1	1.2	1.1	1.1
27	Night	6	6	6	6	1	5	1	1.2	7
28	Night	7	5	7	7	7	7	6	6	7
29	Night	5	5	5	7	7	7	5	7	6
30	Night	1	5	5	1	7	6	7	7	5
31	Night	5	5	1	1	5	5	5	5	1.1

APPENDIX B. RESULT TABULATIONS

The following tables were created to offer useful comparisons for the results. The bar charts in Chapter III were produced from these tabulations.

Table 19. The four month and monthly totals, for reports with full (covered) or nearly full (mostly covered) coverage of higher cloud, in each area of interest.

COVERED AND MOSTLY COVERED TOTALS									
OVERALL TOTALS									
	1	2	3	4	5	6	7	8	9
Covered	177	178	135	138	148	154	160	161	194
Mostly Covered	41	37	60	38	60	54	41	37	42
January									
	1	2	3	4	5	6	7	8	9
Covered	35	36	31	22	25	29	39	35	41
Mostly Covered	5	7	12	5	18	11	13	11	13
April									
	1	2	3	4	5	6	7	8	9
Covered	56	54	41	48	46	43	42	44	54
Mostly Covered	14	13	14	12	20	15	13	11	8
July									
	1	2	3	4	5	6	7	8	9
Covered	57	57	39	40	54	56	49	52	66
Mostly Covered	13	7	20	10	9	10	6	3	11
October									
	1	2	3	4	5	6	7	8	9
Covered	29	31	24	28	23	26	30	30	33
Mostly Covered	9	10	14	11	13	18	9	12	10

Table 20. The four month and monthly totals, for fog and fog likely days, in each area of interest.

FOG AND FOG LIKELY TOTALS									
OVERALL TOTALS									
	1	2	3	4	5	6	7	8	9
Fog	72	67	69	77	77	80	77	85	72
Fog Likely	13	12	13	26	16	13	12	10	9
January									
	1	2	3	4	5	6	7	8	9
Fog	16	12	11	16	18	17	15	20	18
Fog Likely	1	1	2	6	4	3	6	3	2
April									
	1	2	3	4	5	6	7	8	9
Fog	14	12	13	15	13	15	15	17	13
Fog Likely	4	6	6	9	5	8	3	5	3
July									
	1	2	3	4	5	6	7	8	9
Fog	18	20	20	20	20	22	25	23	17
Fog Likely	5	3	4	8	6	1	3	2	4
October									
	1	2	3	4	5	6	7	8	9
Fog	24	23	25	26	26	26	22	25	24
Fog Likely	3	2	1	3	1	1	0	0	0

Table 21. The four month and monthly totals, for fog and fog likely days separated by daytime and nighttime images, for each area of interest.

		DAY VS NIGHT FOG TOTALS							
		OVERALL TOTALS							
Day		1	2	3	4	5	6	7	8	9
Fog		45	48	45	40	43	49	44	53	46
Fog Likely		6	8	15	29	13	10	11	6	6
Night										
Fog		62	56	58	71	70	75	70	75	61
Fog Likely		11	5	6	14	11	8	11	12	7
		JANUARY TOTALS							
Day		1	2	3	4	5	6	7	8	9
Fog		8	9	7	11	10	10	8	11	11
Fog Likely		1	1	2	6	2	4	2	2	0
Night										
Fog		15	9	11	16	16	16	14	15	13
Fog Likely		1	0	1	3	3	1	5	5	3
		APRIL TOTALS							
Day		1	2	3	4	5	6	7	8	9
Fog		7	7	8	4	3	8	4	9	5
Fog Likely		2	4	7	10	6	4	5	2	3
Night										
Fog		9	9	9	14	12	13	14	15	11
Fog Likely		4	2	4	4	1	6	3	5	2
		JULY TOTALS							
Day		1	2	3	4	5	6	7	8	9
Fog		12	12	11	9	11	13	13	15	10
Fog Likely		0	1	5	9	2	2	4	2	2
Night										
Fog		17	19	20	20	19	22	22	22	16
Fog Likely		5	3	1	6	6	0	2	1	2
		OCTOBER TOTALS							
Day		1	2	3	4	5	6	7	8	9
Fog		18	20	19	16	19	18	19	18	20
Fog Likely		3	2	1	4	3	0	0	0	1
Night										
Fog		21	19	18	21	23	24	20	23	21
Fog Likely		1	0	0	1	1	1	1	1	0

Table 22. The four month and monthly totals, for fog and fog likely days separated by Aqua and Terra images, for each area of interest.

				AQUA VS TERA FOG TOTALS					
				OVERALL TOTALS					
Tera	1	2	3	4	5	6	7	8	9
Fog	59	55	51	54	60	63	59	68	54
Fog Likely	7	7	15	22	16	12	14	9	8
Aqua									
Fog	55	56	54	64	62	66	63	70	58
Fog Likely	11	9	13	22	9	9	6	10	6
				JANUARY TOTALS					
Tera	1	2	3	4	5	6	7	8	9
Fog	13	11	10	15	15	16	12	15	16
Fog Likely	0	2	2	4	4	4	3	3	1
Aqua									
Fog	12	10	9	15	14	14	12	15	10
Fog Likely	2	1	2	3	2	0	4	6	3
				APRIL TOTALS					
Tera	1	2	3	4	5	6	7	8	9
Fog	12	9	7	8	8	10	10	14	7
Fog Likely	2	3	6	8	7	4	6	3	2
Aqua									
Fog	7	7	11	11	8	10	9	14	11
Fog Likely	3	4	3	8	3	7	1	2	1
				JULY TOTALS					
Tera	1	2	3	4	5	6	7	8	9
Fog	16	19	18	14	16	15	19	21	13
Fog Likely	2	0	4	8	4	3	4	2	4
Aqua									
Fog	13	17	14	15	16	18	21	18	15
Fog Likely	4	3	6	8	4	2	1	2	1
				OCTOBER TOTALS					
Tera	1	2	3	4	5	6	7	8	9
Fog	18	16	16	17	21	22	18	18	18
Fog Likely	3	2	3	2	1	1	1	1	1
Aqua									
Fog	23	22	20	23	24	24	21	23	22
Fog Likely	2	1	2	3	0	0	0	0	1

Table 23. The four month totals for all fog categories in each area of interest.

		FOUR MONTH OVERALL TOTALS						
	1	2	3	4	5	6	7	8	9
Fog Inland	68	45	31	67	166	56	28	22	57
Coastal Fog	30	51	45	31	0	65	80	98	39
Both Fog Types	54	59	66	59	0	58	64	71	53
Fog Likely	30	18	40	69	42	30	35	32	22
Fog Possible	4	6	7	12	9	4	6	5	4
Fog Unlikely	9	7	12	10	8	10	8	8	3
No Fog	78	90	94	64	58	60	69	57	77
Covered	177	178	135	138	148	154	160	161	194
Mostly Covered	41	37	60	38	60	54	41	37	42
ND	1	1	2	4	1	1	1	1	1

Table 24. The four month daytime image totals for all fog categories in each area of interest.

		FOUR MONTH DAYTIME TOTALS							
	1	2	3	4	5	6	7	8	9
Fog Inland	27	20	13	26	68	18	5	7	21
Coastal Fog	20	37	26	18	0	40	40	55	28
Both Fog Types	19	22	29	15	0	20	24	22	22
Fog Likely	18	12	26	47	27	19	22	16	11
Fog Possible	4	5	5	11	9	4	5	5	4
Fog Unlikely	9	7	11	9	7	10	6	6	3
No Fog	43	47	49	35	34	34	42	37	47
Covered	87	81	60	68	74	77	81	77	95
Mostly Covered	18	14	25	15	26	23	20	20	14
ND	1	1	2	2	1	1	1	1	1

Table 25. The four month nighttime image totals for all fog categories, in each area of interest.

		FOUR MONTH NIGHTTIME TOTALS						
	1	2	3	4	5	6	7	8	9
Fog Inland	41	25	18	41	98	38	23	15	36
Coastal Fog	10	14	19	13	0	25	40	43	11
Both Fog Types	35	37	37	44	0	38	40	49	31
Fog Likely	12	6	14	22	15	11	13	16	11
Fog Possible	0	1	2	1	0	0	1	0	0
Fog Unlikely	0	0	1	1	1	0	2	2	0
No Fog	35	43	45	29	24	26	27	20	30
Covered	90	97	75	70	74	77	79	84	99
Mostly Covered	23	23	35	23	34	31	21	17	28
ND	0	0	0	2	0	0	0	0	0

Table 26. The four month Aqua image totals for all fog categories in each area of interest.

		FOUR MONTH AQUA TOTALS							
	1	2	3	4	5	6	7	8	9
Fog Inland	21	38	27	21	2	41	43	58	30
Coastal Fog	24	26	35	20	4	23	25	22	24
Both Fog Types	29	24	40	57	36	26	33	26	22
Fog Likely	39	37	24	37	39	36	37	37	43
Fog Possible	18	14	21	16	18	21	14	14	7
Fog Unlikely	44	48	51	37	35	35	43	38	48
No Fog	87	81	60	68	74	77	81	77	95
Covered	36	26	31	33	67	40	32	28	32
Mostly Covered	3	8	10	6	1	11	18	17	6
ND	14	17	17	20	0	16	18	22	18

The four month Terra image totals for all fog categories in each area of interest.

		FOUR MONTH TERA TOTALS							
	1	2	3	4	5	6	7	8	9
Fog Inland	7	6	5	8	6	4	4	2	3
Coastal Fog	2	0	1	1	4	1	0	0	0
Both Fog Types	5	7	10	8	9	13	16	16	18
Fog Likely	102	79	60	94	194	84	54	54	96
Fog Possible	39	61	58	44	11	77	92	107	50
Fog Unlikely	56	60	67	61	1	60	65	74	54
No Fog	30	18	40	69	42	30	35	32	22
Covered	10	11	9	16	29	8	10	9	11
Mostly Covered	22	18	27	23	23	24	22	24	8
ND	89	100	104	76	58	71	82	74	85

Table 27. The monthly totals for all fog categories in each area of interest.

MONTHLY TOTALS									
				JANUARY Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	9	8	6	16	36	13	6	1	10
Coastal Fog	10	6	3	12	0	17	11	16	9
Both Fog Types	13	13	17	16	0	9	10	21	14
Fog Likely	6	2	6	11	10	6	10	13	5
Fog Possible	0	0	2	5	1	0	0	1	0
Fog Unlikely	2	3	2	3	1	5	4	6	1
No Fog	44	49	45	34	33	34	31	20	31
Covered	35	36	31	22	25	29	39	35	41
Mostly Covered	5	7	12	5	18	11	13	11	13
ND	0	0	0	0	0	0	0	0	0
				April Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	5	4	1	5	17	6	2	2	7
Coastal Fog	6	11	13	6	0	15	13	22	11
Both Fog Types	9	4	8	10	0	5	7	9	4
Fog Likely	7	7	13	20	14	13	13	9	6
Fog Possible	3	4	3	4	3	3	3	2	2
Fog Unlikely	4	2	4	2	5	4	3	1	1
No Fog	16	21	23	13	15	16	24	20	27
Covered	56	54	41	48	46	43	42	44	54
Mostly Covered	14	13	14	12	20	15	13	11	8
ND	0	0	0	0	0	0	0	0	0
				July Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	8	6	4	9	44	5	5	6	18
Coastal Fog	9	21	20	7	0	22	29	32	4
Both Fog Types	24	24	21	23	0	20	21	20	16
Fog Likely	9	5	15	29	12	9	9	8	5
Fog Possible	1	2	2	3	2	1	3	2	2
Fog Unlikely	2	1	1	2	2	0	0	0	1
No Fog	0	0	1	0	0	0	1	0	0
Covered	57	57	39	40	54	56	49	52	66
Mostly Covered	13	7	20	10	9	10	6	3	11
ND	1	1	1	1	1	1	1	1	1
				October Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	46	27	20	37	69	32	15	13	22
Coastal Fog	5	13	9	6	0	11	27	28	15
Both Fog Types	8	18	20	10	0	24	26	21	19
Fog Likely	8	4	6	9	6	2	3	2	6
Fog Possible	0	0	0	0	3	0	0	0	0
Fog Unlikely	1	1	5	3	0	1	1	1	0
No Fog	18	20	25	17	10	10	13	17	19
Covered	29	31	24	28	23	26	30	30	33
Mostly Covered	9	10	14	11	13	18	9	12	10
ND	0	0	1	3	0	0	0	0	0

Table 28. The monthly daytime and nighttime image totals for all fog categories, in each area of interest.

MONTHLY DAYTIME TOTALS

JANUARY Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	3	5	3	6	14	3	2	0	2
Coastal Fog	4	6	1	8	0	11	4	10	9
Both Fog Types	5	5	8	4	0	2	3	8	7
Fog Likely	4	2	3	7	6	5	4	5	1
Fog Possible	0	0	2	5	1	0	0	1	0
Fog Unlikely	2	3	2	3	1	5	4	6	1
No Fog	22	24	23	15	19	18	20	11	20
Covered	19	15	14	13	11	11	17	13	16
Mostly Covered	3	2	6	1	10	7	8	8	6
ND	0	0	0	0	0	0	0	0	0

April Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	2	0	1	2	4	2	0	0	1
Coastal Fog	6	7	7	2	0	10	5	12	6
Both Fog Types	3	1	3	2	0	0	0	1	2
Fog Likely	3	5	8	13	10	6	9	4	3
Fog Possible	3	4	2	4	3	3	2	2	2
Fog Unlikely	4	2	3	2	4	4	1	0	1
No Fog	9	12	12	9	10	10	17	16	17
Covered	24	23	18	22	22	22	21	21	25
Mostly Covered	6	6	6	4	7	3	5	4	3
ND	0	0	0	0	0	0	0	0	0

July Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	3	2	0	3	17	1	1	1	7
Coastal Fog	5	13	12	4	0	11	13	17	3
Both Fog Types	8	8	6	5	0	7	7	6	5
Fog Likely	4	1	10	19	6	7	7	6	2
Fog Possible	1	1	1	2	2	1	3	2	2
Fog Unlikely	2	1	1	2	2	0	0	0	1
No Fog	0	0	0	0	0	0	0	0	0
Covered	32	32	21	20	29	29	27	28	37
Mostly Covered	6	3	10	6	5	5	3	1	4
ND	1	1	1	1	1	1	1	1	1

October Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	19	13	9	15	33	12	2	6	11
Coastal Fog	5	11	6	4	0	8	18	16	10
Both Fog Types	3	8	12	4	0	11	14	7	8
Fog Likely	7	4	5	8	5	1	2	1	5
Fog Possible	0	0	0	0	3	0	0	0	0
Fog Unlikely	1	1	5	2	0	1	1	0	0
No Fog	12	11	14	11	5	6	5	10	10
Covered	12	11	7	13	12	15	16	15	17
Mostly Covered	3	3	3	4	4	8	4	7	1
ND	0	0	1	1	0	0	0	0	0

MONTHLY NIGHTTIME TOTALS

JANUARY Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	6	3	3	10	22	10	4	1	8
Coastal Fog	6	0	2	4	0	6	7	6	0
Both Fog Types	8	8	9	12	0	7	7	13	7
Fog Likely	2	0	3	4	4	1	6	8	4
Fog Possible	0	0	0	0	0	0	0	0	0
Fog Unlikely	0	0	0	0	0	0	0	0	0
No Fog	22	25	22	19	14	16	11	9	11
Covered	16	21	17	9	14	18	22	22	25
Mostly Covered	2	5	6	4	8	4	5	3	7
ND	0	0	0	0	0	0	0	0	0

April Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	3	4	0	3	13	4	2	2	6
Coastal Fog	0	4	6	4	0	5	8	10	5
Both Fog Types	6	3	5	8	0	5	7	8	2
Fog Likely	4	2	5	7	4	7	4	5	3
Fog Possible	0	0	1	0	0	0	1	0	0
Fog Unlikely	0	0	1	0	1	0	2	1	0
No Fog	7	9	11	4	5	6	7	4	10
Covered	32	31	23	26	24	21	21	23	29
Mostly Covered	8	7	8	8	13	12	8	7	5
ND	0	0	0	0	0	0	0	0	0

July Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	5	4	4	6	27	4	4	5	11
Coastal Fog	4	8	8	3	0	11	16	15	1
Both Fog Types	16	16	15	18	0	13	14	14	11
Fog Likely	5	4	5	10	6	2	2	2	3
Fog Possible	0	1	1	1	0	0	0	0	0
Fog Unlikely	0	0	0	0	0	0	0	0	0
No Fog	0	0	1	0	0	0	1	0	0
Covered	25	25	18	20	25	27	22	24	29
Mostly Covered	7	4	10	4	4	5	3	2	7
ND	0	0	0	0	0	0	0	0	0

October Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	27	14	11	22	36	20	13	7	11
Coastal Fog	0	2	3	2	0	3	9	12	5
Both Fog Types	5	10	8	6	0	13	12	14	11
Fog Likely	1	0	1	1	1	1	1	1	1
Fog Possible	0	0	0	0	0	0	0	0	0
Fog Unlikely	0	0	0	1	0	0	0	1	0
No Fog	6	9	11	6	5	4	8	7	9
Covered	17	20	17	15	11	11	14	15	16
Mostly Covered	6	7	11	7	9	10	5	5	9
ND	0	0	0	2	0	0	0	0	0

Table 29. The monthly Aqua and Terra image totals for all fog categories, in each area of interest.

MONTHLY AQUA TOTALS

JANUARY Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	4	6	2	5	18	6	2	1	5
Coastal Fog	5	2	3	6	0	7	6	7	2
Both Fog Types	6	7	8	9	0	5	6	12	7
Fog Likely	4	1	3	4	5	1	5	7	3
Fog Possible	0	0	1	3	0	0	0	1	0
Fog Unlikely	1	2	1	2	0	3	2	3	1
No Fog	22	23	22	19	20	20	15	8	15
Covered	18	17	15	11	12	15	19	17	23
Mostly Covered	2	4	7	3	7	5	7	6	6
ND	0	0	0	0	0	0	0	0	0

April Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	0	1	1	4	8	3	0	1	5
Coastal Fog	3	6	8	2	0	7	5	8	6
Both Fog Types	5	2	4	6	0	2	5	6	3
Fog Likely	3	4	7	10	5	8	5	4	3
Fog Possible	1	1	2	3	0	1	3	2	1
Fog Unlikely	3	2	2	2	3	3	1	0	1
No Fog	9	12	11	6	8	7	12	9	10
Covered	29	26	20	24	23	21	23	23	25
Mostly Covered	7	6	5	3	13	8	6	7	6
ND	0	0	0	0	0	0	0	0	0

July Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	2	2	2	4	20	2	2	2	8
Coastal Fog	4	11	7	4	0	12	15	14	2
Both Fog Types	10	11	10	12	0	9	11	9	9
Fog Likely	7	3	10	13	6	4	3	5	1
Fog Possible	0	0	0	0	1	0	1	1	1
Fog Unlikely	1	1	1	1	1	0	0	0	1
No Fog	0	0	0	0	0	0	1	0	0
Covered	28	29	19	22	29	29	24	28	32
Mostly Covered	9	4	12	5	4	5	4	2	7
ND	1	1	1	1	1	1	1	1	1

October Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	25	14	10	21	37	18	10	8	12
Coastal Fog	2	8	4	4	0	6	16	16	8
Both Fog Types	5	11	12	7	0	13	12	14	13
Fog Likely	4	2	3	4	3	0	0	0	4
Fog Possible	0	0	0	0	1	0	0	0	0
Fog Unlikely	1	1	3	3	0	0	0	1	0
No Fog	6	5	11	5	3	3	4	2	4
Covered	15	16	10	11	10	11	14	15	17
Mostly Covered	4	5	8	5	8	11	6	6	4
ND	0	0	1	2	0	0	0	0	0

MONTHLY TERA TOTALS

JANUARY Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	5	2	4	11	18	7	4	0	5
Coastal Fog	5	4	0	6	0	10	5	9	7
Both Fog Types	7	6	9	7	0	4	4	9	7
Fog Likely	2	1	3	7	5	5	5	6	2
Fog Possible	0	0	1	2	1	0	0	0	0
Fog Unlikely	1	1	1	1	1	2	2	3	0
No Fog	22	26	23	15	13	14	16	12	16
Covered	17	19	16	11	13	14	20	18	18
Mostly Covered	3	3	5	2	11	6	6	5	7
ND	0	0	0	0	0	0	0	0	0

April Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	5	3	0	1	9	3	2	1	2
Coastal Fog	3	5	5	4	0	8	8	14	5
Both Fog Types	4	2	4	4	0	3	2	3	1
Fog Likely	4	3	6	10	9	5	8	5	3
Fog Possible	2	3	1	1	3	2	0	0	1
Fog Unlikely	1	0	2	0	2	1	2	1	0
No Fog	7	9	12	7	7	9	12	11	17
Covered	27	28	21	24	23	22	19	21	29
Mostly Covered	7	7	9	9	7	7	7	4	2
ND	0	0	0	0	0	0	0	0	0

July Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	6	4	2	5	24	3	3	4	10
Coastal Fog	5	10	13	3	0	10	14	18	2
Both Fog Types	14	13	11	11	0	11	10	11	7
Fog Likely	2	2	5	16	6	5	6	3	4
Fog Possible	1	2	2	3	1	1	2	1	1
Fog Unlikely	1	0	0	1	1	0	0	0	0
No Fog	0	0	1	0	0	0	0	0	0
Covered	29	28	20	18	25	27	25	24	34
Mostly Covered	4	3	8	5	5	5	2	1	4
ND	0	0	0	0	0	0	0	0	0

October Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	21	13	10	16	32	14	5	5	10
Coastal Fog	3	5	5	2	0	5	11	12	7
Both Fog Types	3	7	8	3	0	11	14	7	6
Fog Likely	4	2	3	5	3	2	3	2	2
Fog Possible	0	0	0	0	2	0	0	0	0
Fog Unlikely	0	0	2	0	0	1	1	0	0
No Fog	12	15	14	12	7	7	9	15	15
Covered	14	15	14	17	13	15	16	15	16
Mostly Covered	5	5	6	6	5	7	3	6	6
ND	0	0	0	1	0	0	0	0	0

Table 30. The January and April totals for all fog categories, broken down by individual satellite passes for each area of interest.

JANUARY TOTALS

AQUA DAYTIME Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	1	3	1	2	6	1	0	0	2
Coastal Fog	2	2	1	4	0	5	2	4	2
Both Fog Types	1	2	3	1	0	0	1	4	3
Fog Likely	3	1	1	2	3	1	3	3	1
Fog Possible	0	0	1	3	0	0	0	1	0
Fog Unlikely	1	2	1	2	0	3	2	3	1
No Fog	12	12	13	10	12	11	10	4	9
Covered	10	8	7	6	6	6	8	6	8
Mostly Covered	1	1	3	1	4	4	5	6	5
ND	0	0	0	0	0	0	0	0	0

AQUA NIGHTTIME Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	3	3	1	3	12	5	2	1	3
Coastal Fog	3	0	2	2	0	2	4	3	0
Both Fog Types	5	5	5	8	0	5	5	8	4
Fog Likely	1	0	2	2	2	0	2	4	2
Fog Possible	0	0	0	0	0	0	0	0	0
Fog Unlikely	0	0	0	0	0	0	0	0	0
No Fog	10	11	9	9	8	9	5	4	6
Covered	8	9	8	5	6	9	11	11	15
Mostly Covered	1	3	4	2	3	1	2	0	1
ND	0	0	0	0	0	0	0	0	0

TERA DAYTIME Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	2	2	2	4	8	2	2	0	0
Coastal Fog	2	4	0	4	0	6	2	6	7
Both Fog Types	4	3	5	3	0	2	2	4	4
Fog Likely	1	1	2	5	3	4	1	2	0
Fog Possible	0	0	1	2	1	0	0	0	0
Fog Unlikely	1	1	1	1	1	2	2	3	0
No Fog	10	12	10	5	7	7	10	7	11
Covered	9	7	7	7	5	5	9	7	8
Mostly Covered	2	1	3	0	6	3	3	2	1
ND	0	0	0	0	0	0	0	0	0

TERA NIGHTTIME Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	3	0	2	7	10	5	2	0	5
Coastal Fog	3	0	0	2	0	4	3	3	0
Both Fog Types	3	3	4	4	0	2	2	5	3
Fog Likely	1	0	1	2	2	1	4	4	2
Fog Possible	0	0	0	0	0	0	0	0	0
Fog Unlikely	0	0	0	0	0	0	0	0	0
No Fog	12	14	13	10	6	7	6	5	5
Covered	8	12	9	4	8	9	11	11	10
Mostly Covered	1	2	2	2	5	3	3	3	6
ND	0	0	0	0	0	0	0	0	0

APRIL TOTALS

AQUA DAYTIME Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	0	0	1	1	1	1	0	0	1
Coastal Fog	3	3	4	1	0	4	1	4	2
Both Fog Types	1	0	0	1	0	0	0	1	1
Fog Likely	1	3	5	7	4	4	4	2	3
Fog Possible	1	1	1	3	0	1	2	2	1
Fog Unlikely	3	2	2	2	3	3	1	0	1
No Fog	5	7	7	5	6	4	9	8	8
Covered	12	11	8	9	10	11	11	10	12
Mostly Covered	4	3	2	1	6	2	2	3	1
ND	0	0	0	0	0	0	0	0	0

AQUA NIGHTTIME Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	0	1	0	3	7	2	0	1	4
Coastal Fog	0	3	4	1	0	3	4	4	4
Both Fog Types	4	2	4	5	0	2	5	5	2
Fog Likely	2	1	2	3	1	4	1	2	0
Fog Possible	0	0	1	0	0	0	1	0	0
Fog Unlikely	0	0	0	0	0	0	0	0	0
No Fog	4	5	4	1	2	3	3	1	2
Covered	17	15	12	15	13	10	12	13	13
Mostly Covered	3	3	3	2	7	6	4	4	5
ND	0	0	0	0	0	0	0	0	0

TERA DAYTIME Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	2	0	0	1	3	1	0	0	0
Coastal Fog	3	4	3	1	0	6	4	8	4
Both Fog Types	2	1	3	1	0	0	0	0	1
Fog Likely	2	2	3	6	6	2	5	2	0
Fog Possible	2	3	1	1	3	2	0	0	1
Fog Unlikely	1	0	1	0	1	1	0	0	0
No Fog	4	5	5	4	4	6	8	8	9
Covered	12	12	10	13	12	11	10	11	13
Mostly Covered	2	3	4	3	1	1	3	1	2
ND	0	0	0	0	0	0	0	0	0

TERA NIGHTTIME Totals

	1	2	3	4	5	6	7	8	9
Fog Inland	3	3	0	0	6	2	2	1	2
Coastal Fog	0	1	2	3	0	2	4	6	1
Both Fog Types	2	1	1	3	0	3	2	3	0
Fog Likely	2	1	3	4	3	3	3	3	3
Fog Possible	0	0	0	0	0	0	0	0	0
Fog Unlikely	0	0	1	0	1	0	2	1	0
No Fog	3	4	7	3	3	3	4	3	8
Covered	15	16	11	11	11	11	9	10	16
Mostly Covered	5	4	5	6	6	6	4	3	0
ND	0	0	0	0	0	0	0	0	0

Table 31. The July and October totals for all fog categories, broken down by individual satellite passes for each area of interest.

				JULY TOTALS					
				AQUA DAYTIME					
				Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	0	0	0	2	7	0	0	0	2
Coastal Fog	2	8	5	2	0	6	6	7	2
Both Fog Types	3	3	3	2	0	2	3	2	2
Fog Likely	4	0	6	7	4	4	3	4	1
Fog Possible	0	0	0	0	1	0	1	1	1
Fog Unlikely	1	1	1	1	1	0	0	0	1
No Fog	0	0	0	0	0	0	0	0	0
Covered	16	16	9	12	15	15	14	15	18
Mostly Covered	4	2	6	4	2	3	3	1	3
ND	1	1	1	1	1	1	1	1	1
				AQUA NIGHTTIME					
				Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	2	2	2	2	13	2	2	2	6
Coastal Fog	2	3	2	2	0	6	9	7	0
Both Fog Types	7	8	7	10	0	7	8	7	7
Fog Likely	3	3	4	6	2	0	0	1	0
Fog Possible	0	0	0	0	0	0	0	0	0
Fog Unlikely	0	0	0	0	0	0	0	0	0
No Fog	0	0	0	0	0	0	1	0	0
Covered	12	13	10	10	14	14	10	13	14
Mostly Covered	5	2	6	1	2	2	1	1	4
ND	0	0	0	0	0	0	0	0	0
				TERA DAYTIME					
				Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	3	2	0	1	10	1	1	1	5
Coastal Fog	3	5	7	2	0	5	7	10	1
Both Fog Types	5	5	3	3	0	5	4	4	3
Fog Likely	0	1	4	12	2	3	4	2	1
Fog Possible	1	1	1	2	1	1	2	1	1
Fog Unlikely	1	0	0	1	1	0	0	0	0
No Fog	0	0	0	0	0	0	0	0	0
Covered	16	16	12	8	14	14	13	13	19
Mostly Covered	2	1	4	2	3	2	0	0	1
ND	0	0	0	0	0	0	0	0	0
				TERA NIGHTTIME					
				Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	3	2	2	4	14	2	2	3	5
Coastal Fog	2	5	6	1	0	5	7	8	1
Both Fog Types	9	8	8	8	0	6	6	7	4
Fog Likely	2	1	1	4	4	2	2	1	3
Fog Possible	0	1	1	1	0	0	0	0	0
Fog Unlikely	0	0	0	0	0	0	0	0	0
No Fog	0	0	1	0	0	0	0	0	0
Covered	13	12	8	10	11	13	12	11	15
Mostly Covered	2	2	4	3	2	3	2	1	3
ND	0	0	0	0	0	0	0	0	0

				OCTOBER TOTALS					
				AQUA DAYTIME					
				Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	9	5	6	8	16	5	0	3	4
Coastal Fog	2	7	2	3	0	5	12	11	7
Both Fog Types	2	4	6	2	0	6	7	4	4
Fog Likely	3	2	2	3	3	0	0	0	4
Fog Possible	0	0	0	0	1	0	0	0	0
Fog Unlikely	1	1	3	2	0	0	0	0	0
No Fog	6	5	7	5	3	3	2	2	3
Covered	7	5	2	5	5	6	7	7	9
Mostly Covered	1	2	2	2	3	6	3	4	0
ND	0	0	1	1	0	0	0	0	0
				AQUA NIGHTTIME					
				Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	16	9	4	13	21	13	10	5	8
Coastal Fog	0	1	2	1	0	1	4	5	1
Both Fog Types	3	7	6	5	0	7	5	10	9
Fog Likely	1	0	1	1	0	0	0	0	0
Fog Possible	0	0	0	0	0	0	0	0	0
Fog Unlikely	0	0	0	1	0	0	0	1	0
No Fog	0	0	4	0	0	0	2	0	1
Covered	8	11	8	6	5	5	7	8	8
Mostly Covered	3	3	6	3	5	5	3	2	4
ND	0	0	0	1	0	0	0	0	0
				TERA DAYTIME					
				Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	10	8	3	7	17	7	2	3	7
Coastal Fog	3	4	4	1	0	3	6	5	3
Both Fog Types	1	4	6	2	0	5	7	3	4
Fog Likely	4	2	3	5	2	1	2	1	1
Fog Possible	0	0	0	0	2	0	0	0	0
Fog Unlikely	0	0	2	0	0	1	1	0	0
No Fog	6	6	7	6	2	3	3	8	7
Covered	5	6	5	8	7	9	9	8	8
Mostly Covered	2	1	1	2	1	2	1	3	1
ND	0	0	0	0	0	0	0	0	0
				TERA NIGHTTIME					
				Totals					
	1	2	3	4	5	6	7	8	9
Fog Inland	11	5	7	9	15	7	3	2	3
Coastal Fog	0	1	1	1	0	2	5	7	4
Both Fog Types	2	3	2	1	0	6	7	4	2
Fog Likely	0	0	0	0	1	1	1	1	1
Fog Possible	0	0	0	0	0	0	0	0	0
Fog Unlikely	0	0	0	0	0	0	0	0	0
No Fog	6	9	7	6	5	4	6	7	8
Covered	9	9	9	9	6	6	7	7	8
Mostly Covered	3	4	5	4	4	5	2	3	5
ND	0	0	0	1	0	0	0	0	0

Table 32. The monthly fog and fog likely totals broken down by the individual satellite passes for comparison with Guttman (1978).

	Number of Fog Days															
	January				April				July				October			
Area	TD	AD	TN	AN	TD	AD	TN	AN	TD	AD	TN	AN	TD	AD	TN	AN
	0130 UTC	0430 UTC	1330 UTC	1630 UTC	0130 UTC	0430 UTC	1330 UTC	1630 UTC	0130 UTC	0430 UTC	1330 UTC	1630 UTC	0130 UTC	0430 UTC	1330 UTC	1630 UTC
1	8.00	4.00	9.00	11.00	7.00	4.00	5.00	4.00	11.00	5.00	14.00	4.00	14.00	13.00	13.00	19.00
2	9.00	7.00	3.00	8.00	5.00	3.00	5.00	6.00	12.00	11.00	15.00	6.00	16.00	16.00	9.00	17.00
3	7.00	5.00	6.00	8.00	6.00	5.00	3.00	8.00	10.00	8.00	16.00	8.00	13.00	14.00	10.00	12.00
4	11.00	7.00	13.00	13.00	3.00	3.00	6.00	9.00	6.00	6.00	13.00	9.00	10.00	13.00	11.00	19.00
5	8.00	6.00	10.00	12.00	3.00	1.00	6.00	7.00	10.00	7.00	14.00	7.00	17.00	16.00	15.00	21.00
6	10.00	6.00	11.00	12.00	7.00	5.00	7.00	7.00	11.00	8.00	13.00	7.00	15.00	16.00	15.00	21.00
7	6.00	3.00	7.00	11.00	4.00	1.00	8.00	9.00	12.00	9.00	15.00	9.00	15.00	19.00	15.00	19.00
8	10.00	8.00	8.00	12.00	8.00	5.00	10.00	10.00	15.00	9.00	18.00	10.00	11.00	18.00	13.00	20.00
9	11.00	7.00	8.00	7.00	5.00	4.00	3.00	10.00	9.00	6.00	10.00	10.00	14.00	15.00	9.00	18.00
	Number of Fog Likely Days															
	January				April				July				October			
Area	TD	AD	TN	AN	TD	AD	TN	AN	TD	AD	TN	AN	TD	AD	TN	AN
	0130 UTC	0430 UTC	1330 UTC	1630 UTC	0130 UTC	0430 UTC	1330 UTC	1630 UTC	0130 UTC	0430 UTC	1330 UTC	1630 UTC	0130 UTC	0430 UTC	1330 UTC	1630 UTC
1	1.00	3.00	1.00	1.00	2.00	1.00	2.00	2.00	0.00	4.00	2.00	3.00	4.00	3.00	0.00	1.00
2	1.00	1.00	0.00	0.00	2.00	3.00	1.00	1.00	1.00	0.00	1.00	3.00	2.00	2.00	0.00	0.00
3	2.00	1.00	1.00	2.00	3.00	5.00	3.00	2.00	4.00	6.00	1.00	4.00	3.00	2.00	0.00	1.00
4	5.00	2.00	2.00	2.00	6.00	7.00	4.00	3.00	12.00	7.00	4.00	6.00	5.00	3.00	0.00	1.00
5	3.00	3.00	2.00	2.00	6.00	4.00	3.00	1.00	2.00	4.00	4.00	2.00	2.00	3.00	1.00	0.00
6	4.00	1.00	1.00	0.00	2.00	4.00	3.00	4.00	3.00	4.00	2.00	0.00	1.00	0.00	1.00	0.00
7	1.00	3.00	4.00	2.00	5.00	4.00	3.00	1.00	4.00	3.00	2.00	0.00	2.00	0.00	1.00	0.00
8	2.00	3.00	4.00	4.00	2.00	2.00	3.00	2.00	2.00	4.00	1.00	1.00	1.00	0.00	1.00	0.00
9	0.00	1.00	2.00	2.00	0.00	3.00	3.00	0.00	1.00	1.00	3.00	0.00	1.00	4.00	1.00	0.00

Table 33. The maximum average monthly fog days for each area of interest at 00, 06, 12, and 18 UTC (after Guttman 1978).

	NAVY															
	Mean Fog Days															
	January				April				July				October			
Area	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z
1	12.96	4.34	4.59	6.79	5.79	1.35	1.89	1.41	7.87	2.17	2.51	5.55	14.34	3.39	1.47	4.65
2	17.79	9.08	9.98	10.82	13.89	5.55	7.38	9.63	12.49	6.29	9.73	11.47	17.22	5.82	6.30	9.03
3	17.95	11.10	8.09	12.15	15.51	3.69	2.34	7.11	12.15	3.19	3.38	10.60	17.34	5.97	3.51	10.80
4	5.15	2.48	3.69	3.19	5.04	2.79	3.42	3.93	8.40	2.95	3.72	7.38	4.98	1.38	1.50	1.95
5	12.43	4.25	1.77	2.70	9.39	1.38	1.41	1.98	10.73	1.92	1.77	5.55	14.70	1.05	0.84	2.43
6	5.02	0.71	0.96	0.59	5.40	2.73	2.64	2.52	9.24	6.08	5.33	5.52	5.76	1.20	1.71	1.35
7	3.47	1.27	1.27	0.68	7.08	2.43	2.28	2.94	8.53	3.97	4.68	6.70	4.80	1.08	1.29	1.29
8	10.85	3.44	2.05	1.77	11.70	2.40	1.56	2.91	7.50	2.54	3.10	3.41	15.42	0.90	1.11	1.50
9	17.27	6.05	7.72	12.74	9.69	3.84	4.02	7.74	10.60	5.55	4.87	8.62	17.31	6.27	7.11	9.54

Table 34. The maximum average monthly fog days for each area of interest (after Kim and Lee 1970).

	KIM AND LEE				
	MAX MEAN FOG DAYS				
Area		January	April	July	October
1		1	2.4	4.9	8.3
2		5	5	11	3.1
3		3	5.8	14.9	4.7
4		0.9	3.5	9.4	3
5		0.6	1.1	0.9	3
6		1	1.3	5.9	1.9
7		2	3.8	12.1	4.4
8		2	6.6	17.6	3.2
9		3.5	7.3	15.2	4.9

Table 35. The maximum average monthly fog days for each area of interest (after AFCCC 2007).

	AFCCC				
	MAX MEAN FOG DAYS				
Area		January	April	July	October
1		18	20	25	22
2		22	20	25	23
3		21	18	25	21
4		9	12	18	10
5		24	21	26	28
6		16	17	23	22
7		21	20	24	25
8		20	23	24	25
9		23	25	26	27

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